FACTORS OF GOLD CONCENTRATION IN CHAMPION LODE, KOLAR GOLD MINES, KARNATAKA, INDIA

J.V.SUBBARAMAN

Ph.D Thesis Submitted to

SRI VENKATESWARA UNIVERSITY

TIRUPATI - 517 502, INDIA

1999

CERTIFICATE

I certify that the entire work embodied in this thesis has been carried out by **Mr.J.V.Subbaraman** under my guidance in the Department of Geology, Sri Venkateswara University, Tirupati, Andhra Pradesh, India, and that no part of it has been submitted elsewhere for any degree or diploma.

Tirupati
Date: 6-9-1999

V. Damodara Reddy
Research supervisor.

DECLARATION

I hereby declare that the thesis entitled "**Factors of gold concentration in Champion lode, Kolar Gold Mines, Karnataka, India**", is the original research work carried out by me under the supervision of **Prof.V.Damodara Reddy**, Department of Geology, Sri Venkateswara University, Tirupati, Andhra Pradesh India, and that it has not previously formed the basis for the award of any degree or diploma.

(J.V.SUBBARAMAN)

Tirupati
Date: 6.9.99

ABSTRACT

The Kolar Gold Mines in Karnataka has produced more than 770 tonnes of gold since 1880. Because of ultradepth (3.2 km), the gold mining as a commercial venture has become uneconomical and the mines are being phased out. To day India produces 2.5 tonnes of gold and consumes more than 600 tonnes per year. Five decades of gold exploration in the country has not helped in identifying any new gold deposit other than what was known to our ancestors. In this context an analysis of mine geological data relating to the Champion lode of Kolar Gold Mines is presented for identification of geological factors responsible for gold concentration along the strike and depth. For this work extensive observations and notes on the occurrence and localisation of gold and the available mine data in the Survey and Exploration departments of Bharat Gold Mines has been used extensively.

Among the greenstone belts of South India, the Kolar Schist Belt is the most important one in which the Champion lode occurs. Economic concentration of gold is confined to the central part of the schist belt. The Champion lode occurs in komatiite rock in the eastern part of the schist belt. Other sulphidic lodes of lesser importance occur in the tholeiite rock on the western part. The northern part of the schist belt is devoid of any significant gold mineralisation. The southern part of schist belt contains sub-marginal grade deposits.

The Champion lode on surface can be traced for 8 km long but it tapers to 0.5-km length at 3.2-km depth. Thus in a strike section the Champion lode is funnel shaped. This lode dips at 40^{o} - 45^{o}W in the upper levels and in bottom levels it becomes almost vertical. The Champion lode is cut by dolerite dykes and pegmatites. The gold distribution in the Champion lode is highly erratic. Along with the native gold some scheelite, silver, copper etc are associated, out of which silver and scheelite have been recovered as byproducts. The fineness of gold was 880/1000 parts in the upper levels and is 990/1000 parts in the bottom levels.

Gold concentration has been observed at structurally controlled sites and at places often giving rise to nugget formation.

A careful examination of the occurrence of the Champion lode together with the mine geological data has lead to identification of several factors of gold concentration in the Champion lode. These are discussed in detail and conclusions are drawn for reasons of gold localisation in the Champion lode.

ACKNOWLEDGEMENTS

I express my deep gratitude to the following, who helped me in many ways during the course of my present research work:

In the Department of Geology, S.V. University, Tirupati

Prof. R. Jagadiswara Rao Retd. Principal, University College of Arts and Science and Prof. V. Venkatachalapathi, Retd.Prof. of Geology, Mysore University were primarily responsible for my taking up Ph.D. Programme.

To Prof. V. Damodara Reddy, my research supervisor , I find no adequate words to express my gratitude for the three laborious years he spent in correcting repeatedly the draft and providing very useful suggestions in improving the quality.

Prof. C.V.R.K. Prasad, like a good mother-in-law reviewed the draft critically several times to enhance the quality of presentation.

Prof. K.L. Narasimha Rao, Head of the Dept., Prof. E.A.V. Prasad and Prof. P.T. Naidu evinced keen interest in the progress of my work.

In Bharat Gold Mines Limited

Shri R. Gupta, Managing Director, permitted me to make use of mine geological data in Bharat Gold Mines Ltd, Kolar Gold Fields, Karnataka.

S/Shri M.S. Hegde, and C.V. Seshadri, Chief Mining Geologists of Exploration Department were generous in providing reports, maps, etc. required for my work.

Shri R.R.T, Lavi, Retd. Chief Mine Surveyor was kind enough to visit KGF to explain some of the intricate aspects of Mysore Mine area.

In National Institute of Rock Mechanics

Dr. N.M. Raju, Former Director, permitted me to make use of Technical Library.

Dr. Sen Gupta, Scientist, provided the rock pressure measurements of Kolar and Canadian gold mines.

The concerned authorities of Geological Survey of India, AMSE Division, Bangalore and the Geological Society of India, Bangalore for permitting me to make use of the library facilities.

Smt. D. Sumathi of BGML patiently typed several drafts before the final typing of the thesis.

M/s M.R.Goutham, K.Raghu Babu and S.Reginald, my colleagues helped me in finalising the thesis in its present form.

And finally a word of appreciation to my wife Smt. Kantha, who gave all the support and encouragement during the last three years. I specially admire her for tolerating a "truant" husband.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1

INTRODUCTION

CHAPTER-1
INTRODUCTION

Historical background

Among the earth's treasures perhaps gold is the most sought after metal because of its noble characteristics particularly its brilliant, pleasing and untarnishable nature. The name "Gold" is believed to have come from Sanskrit word "Jvalitha" which was derived from "Jval" meaning to shine. The Egyptians used a circle as a symbol for gold. The Greek Sun God "Apollo" was associated with gold and was represented with a circle and a dot in the center (M.H. Govett and M.R. Harrowell, 1982).

Picking up of gold nuggets from alluvial streams was perhaps the first encounter by primitive men more as objects of curiosity than for its nobility. Gold ornaments and artifacts have been found in the excavations of most ancient civilizations world over, signifying the use of gold was prevalent even in the pre-historic periods. The acquisition of gold as a symbol of national and individual status has been a major catalyst for exploration and exploitation of gold deposits all over the world.

The 1998 gold production in the world was 2255 tonnes, out of which India contributed only 2.5 tonnes (0.11%) but consumed 506 tonnes (22.5%). (Source: World Gold Survey 1999). This only shows the great fascination of the Indians for gold. It is believed that the gold demand in India may cross 1000 tonnes by 2001 (R. Gupta & C.V. Seshadri, 1996).

The distribution of gold in the crust of the earth is 4 parts per billion (Robert Davis 1996). It is found in all rock types of all ages. When gold gets concentrated to more than 3 g/t (3 ppm), the rock formation can be considered as auriferous for commercial exploitation. Gold deposits are found throughout the world in the auriferous quartz veins in the Precambrian rocks. Most of these

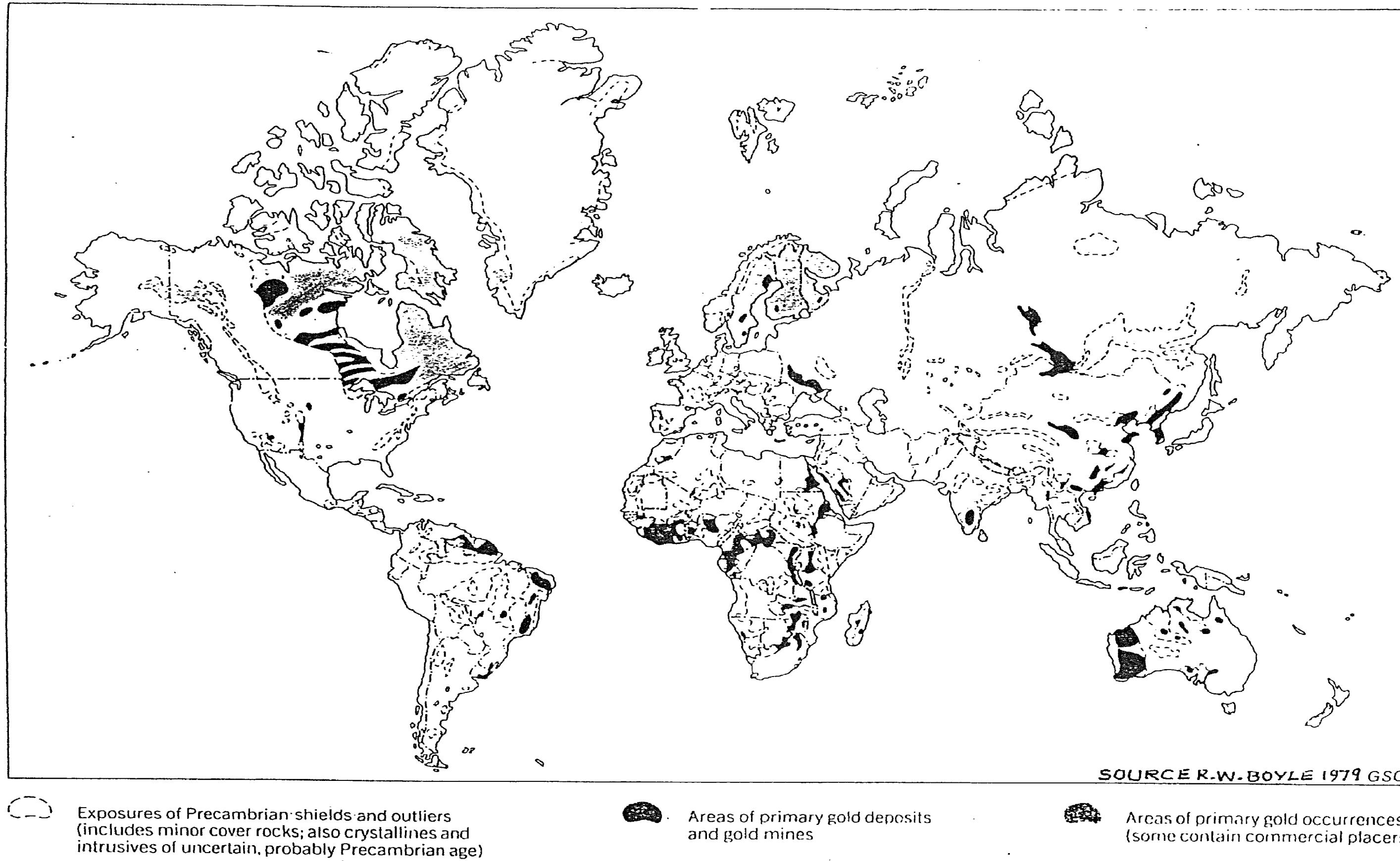
deposits occur in the volcanic rocks and associated sediments in the continents of North America, South America, Africa, Asia and Australia (Fig.1). In the Palaeozoic, Mesozoic and Cenozoic rocks the gold deposits occur in restricted areas in all the continents.

With the realisation of gold as a mark of material status, people all over the world moved out in quest of gold. These are popularly known as "Gold rushes". The most famous ones are the Californian gold rush during 1770's. This is one of the major factors for the migration of people from European countries to North America. Similar gold rushes also took place in Australia (1823), South Africa (1834), Canada (1835), New Zealand (1852) and India (1880). The gold rushes were initially restricted to placer gold along the stream courses and ultimately the search led to the discovery of the source of primary gold deposits. At present the following are the top gold producing countries in the world (Table 1)

Table-1. Top 20 gold producing countries: Ranks and Production (tonnes)

Rank 1998	Rank 1997	Name of the Country	Production 1997	Production 1998
1	1	South Africa	493	474
2	2	U.S.A.	359	364
3	3	Australia	313	313
4	4	Canada	168	164
5	5	China	153	161
6	7	Indonesia (SE)	102	139
7	6	Russia	138	127
8	9	Peru (S.A)	75	89
9	8	Uzbekistan, Europe	83	81
10	11	Ghana, Africa	56	73
11	13	PNG	49	63
12	10	Brazil, S.A	59	55
13	12	Chile, S.A	53	47
14	14	Philippines, SE	34	35
15	15	Zimbabwe, Africa	26	27
16	16	Mexico, C.A.	26	26
17	20	Mali, Africa	17	22
18	19	Kyrgystan, Europe	17	22
19	17	Columbia	22	22
20	47	Argentina	3	22
		Rest of World	235	220
		TOTAL	**2480**	**2555**

Source: Gold Survey 1999

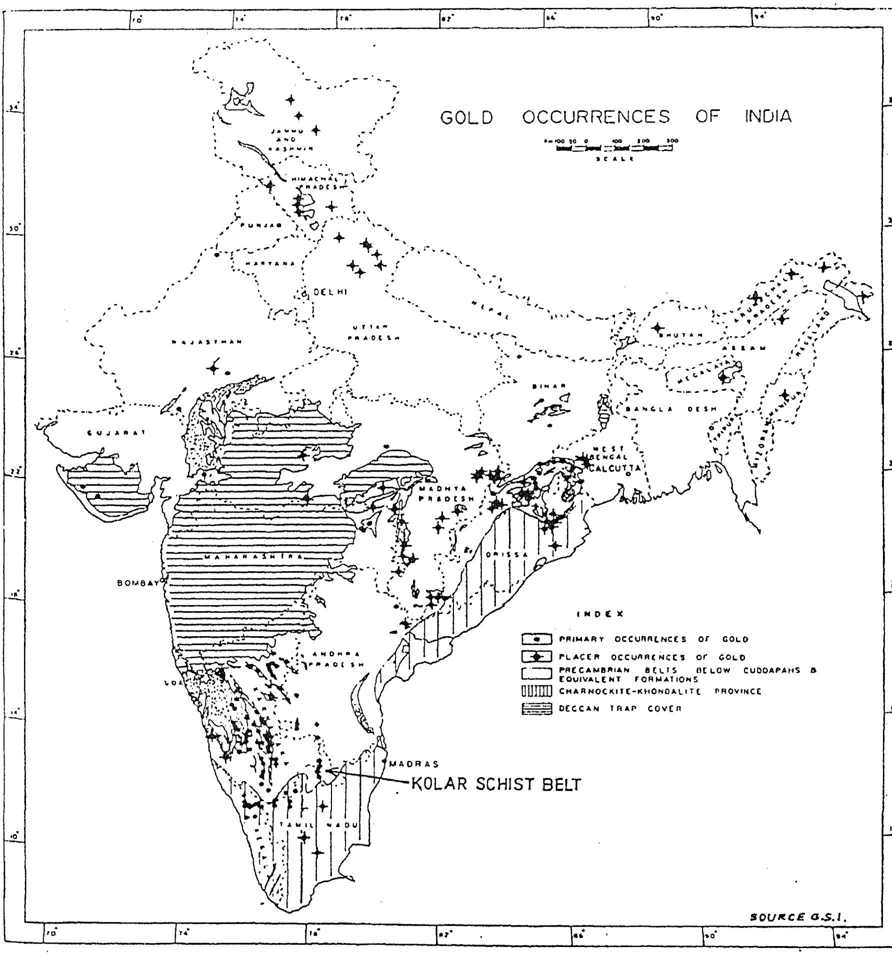


FIG·1 : WORLD DISTRIBUTION OF PRIMARY GOLD DEPOSITS AND OCCURRENCES OF PRECAMBRIAN AGE

In the above table India does not find a place. During the period 1880 - 1980 the Kolar Gold Mines in South India was one of the important gold producing centers with an average of 7.8 tonnes of gold per year. Because of ultradepth of 3.2 km, the mining has become uneconomical and mines are now being phased out. At present India produces the 2.5 tonnes of gold, with breakup of (i) Hutti Gold Mines 1.50 tonnes, (ii) Bharat gold mines Limited from Kolar mines in Karnataka and from Ramagiri, Chigargunta and Bisanatham mines in Andhra Pradesh together producing about 0.7 tonnes and the balance is coming from Hindustan Copper Ltd, etc as a by-product from copper smelters. It is a paradox that India, the largest consumer of gold in the world and with its ever-increasing demand for the yellow metal year after year, does not occupy any significant place as a producer of gold in the world.

By far the richest gold deposits in the world are located in South Africa, which now produce about 18.55% of the world's gold output. Although USA, Australia and Canada still retain their prominent positions as leading gold producers, some of the Asian countries like Russia, China, Indonesia, Uzbekistan and North Korea are now emerging as important gold producers. Similarly some South American countries like Peru, Chile, Mexico, Venezuela, Bolivia and Argentina are other emerging gold producers in the world.

Although there are several known gold occurrences in India practically in all the states, the most significant ones are the Kolar Gold Mines and Hutti Gold Mines both located in Karnataka (Fig.2). Apart from this, on a very negligible scale gold is being recovered by the local tribes and villagers from the streams which drain the auriferous zones in the states of Karnataka, Andhra Pradesh, Kerala, Orissa, Madhya Pradesh, West Bengal, Bihar, Uttar Pradesh and Himachal Pradesh, etc.



GOLD OCCURRENCES OF INDIA
SCALE
JAMMU AND KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
DELHI
RAJASTHAN
UTTAR PRADESH
NEPAL
BHUTAN
ASSAM
BIHAR
BANGLA DESH
WEST BENGAL
CALCUTTA
GUJARAT
MADHYA PRADESH
ORISSA
MAHARASHTRA
BOMBAY
ANDHRA PRADESH
MADRAS
KOLAR SCHIST BELT
TAMIL NADU
INDEX
PRIMARY OCCURRENCES OF GOLD
PLACER OCCURRENCES OF GOLD
PRECAMBRIAN BELTS BELOW CUDDAPAHS & EQUIVALENT FORMATIONS
CHARNOCKITE-KHONDALITE PROVINCE
DECCAN TRAP COVER
SOURCE G.S.I.

FIG.2.

Gold exploration has been going on all over the world by using various techniques. In the beginning all the major gold deposits were discovered by employing direct techniques like geological mapping, pitting, trenching, sampling and drilling, etc. With the continuous exploitation of the known near surface deposits, technological innovations have been adopted for locating concealed ore bodies by the use of geophysical and geochemical methods. Since the demand for gold is increasing, the low-grade ores (less than 2 g/t) are also being considered for exploitation by employing "insitu" and "heap- leaching" of low-grade ore. The researchers in the universities and other national research centers are undertaking lot of fundamental research work in the field of petrology, ore genesis and geochemistry. These researches have thrown new light on the genetics and source rock for gold. Although no new gold deposit has been yet discovered on the basis of this, they have offered new avenues with speculative hypotheses for locating gold at new target areas, especially along subduction zones.

Although there are no major innovations in the field of underground mining for gold, there have been considerable improvement in the open-pit mining leading to substantial increase in the daily output by mechanising many of the mining operations.

Major advances have been made in the recovery of gold particularly from very low-grade ores, which were earlier being discarded, as uneconomical. The heap-leaching technology, carbon-in-pulp technology, bio-leaching technology are some of the new methods that are being currently adopted for gold recovery from low-grade ores. Even in Kolar Gold Mines the heap-leaching technology is being adopted for recovery of a part of the gold found in the 30 million tonnes of mill tailings. As a result the exploration activities all over the world are being stepped up not only to locate new deposits but also to reassess the known resources of low grade ore.

In India this awareness has caught the attention of geoscientists and much work is in progress, particularly in the field of geochemistry and reassessment of the known gold resources. In this context, the nature of occurrence of the lode and an analysis of the mine geological data of the "Champion lode" of the Kolar Gold Mines is presented in this work for identification of geological factors for gold concentration with a discussion on the possible factors and processes for enrichment of gold at different locations along the strike and dip of the Champion lode. It is hoped that this attempt will lead to a better understanding of gold localisation which may help in exploration in other areas in India and elsewhere.

Definition of the Problem:

It is proposed to present identification of the geological structures and other features of the concentration of gold in the Champion lode and discuss the possible factors and processes responsible for their formation. In this attempt the actual observation of the occurrence of the lode and geological data accumulated over several decades of mining and the mine plans, sections, and models are extensively used.

The Champion lode forms a part of the Kolar Schist Belt. This schist belt is mainly made up of amphibolites with several textural types. The Kolar Schist Belt is generally considered as belonging to the older greenstone belt of the Archaean age in the geology of India.

An attempt is made here to classify and identify the geological factors of gold concentration such as shape of orebody, vent of orebody, host rock, types of fracturing, caught up ore shoots, micro fracturing leading to nugget formation, reduced temperature and pressure, intrusion of pegmatites and weathering. Other related structural features such as strike, dip, curvatures of lode, pitch of the ore body, narrowing of the ore body with depth, role of gravity, presence of gouge, faulting, folding, are also discussed.

Methods of Study:

The author has made extensive observations and made notes on the geology of Champion lode and the factors for concentration of gold during his active service in the Kolar Gold Mines from 1954-1960 and 1978-1987. All this information is used here together with the data from mine offices. There are five gold mines (operative or non-operative) namely Balaghat, Nundydroog, Oorgaum, Champion and Mysore mines from north to south on the Champion lode. The mine plans, sections and mine models together with sample data of all the five mines have been extensively used here in chronological order. In order to verify the data available on mine plans and sections about the occurrence of the Champion lode, special underground visits were undertaken to ascertain the nature of host rock and other structural features at different depths. All the linear distances along the strike and dip are given in feet as is available on the original mine records. Similarly all the gold values are given in pennyweights (dwt)/tonne of ore, (one dwt is equal to 1.71 g/t). At places for effective description pennyweights are converted in g/t. Fig.3 is a longitudinal strike section of the entire Kolar Gold Mines, 8 km long and 3.2 km deep which shows the boundaries of the individual mines, the names of shafts sunk, the number and depth (below the field datum) of the levels driven to develop the mines, etc.

All this information along with the voluminous data available in the mine offices is reduced to presentable form by adopting great reduction of size and scale of maps and sections and by making averages of unwieldy assay data. Based on this data the possible factors that have influenced the gold concentration of various types in the Champion lode are discussed. It is for the first time a detailed discussion on the concentration of gold in the Champion lode of Kolar Gold Mines is being presented. In this effort all available data on the mines and the detailed observations and notes on the nature of occurrence and concentration of gold in the Kolar Gold Mines are considered in identifying the gold localisation problems and their causes.

The work is organised into five chapters each with some sections. The first chapter gives a historical background, definition of the problem and methods adopted for the study of the Champion lode are given in detail. The second chapter gives a description of the Kolar Schist Belt and the Kolar Gold Mines along with a review of literature on these. The third chapter gives a detailed discussion on how the Champion lode occurs, its mineralogy, structure, shape, size and the extent of mine developments on it. The fourth chapter gives details of various types of gold concentrations in the Champion lode at various sites and in different structures along with a discussion of factors or processes involved in the concentration. The fifth chapter gives the conclusions reached on the concentration of gold in the Champion lode.

CHAPTER-2

THE KOLAR SCHIST BELT

CHAPTER-2

THE KOLAR SCHIST BELT

The Kolar greenstone belt commonly known as the Kolar Schist Belt (KSB) is the most important gold belt in India having one of the deepest gold mines, which has gone to a maximum depth of 3.2 km. This KSB is situated in the eastern block of Karnataka craton and is characterised as the greenstone belt of "Keewatian type" (Ramakrishna et al 1976) which is distinct from other schist belts in the western part of Karnataka. This belt is different from the classical Barberton type in not having a sedimentary group. However this KSB has resemblance to Barberton type by the predominance of mafic volcanics and encircling of granite plutons (Radhakrishna et al 1984). This belt has some structural similarities to the greenstone belt of superior province of Canada.

The KSB encompasses an area of 300 square kilometers and extends in North - South direction for 80 km from Srinivaspura (13°20' : 78° 13') in North to Maharajagadai (12° 46' : 78° 14') in the South. This schist belt is spread in the three states of South India as follows:

S. No	State	District	Strike Length in km.
1.	Karnataka	Kolar	70
2.	Andhra Pradesh	Chittoor	7
3.	Tamil Nadu	Dharmapuri	3

The width of the schist belt varies from 3 - 4 km. A detailed geological map of KSB is shown in Fig.4.

The mafic and felsic volcanics with subordinate volcanogenic sedimentary sequence represented by Banded Iron Formation (BIF) and graphitic schists constitute the rock types of KSB.

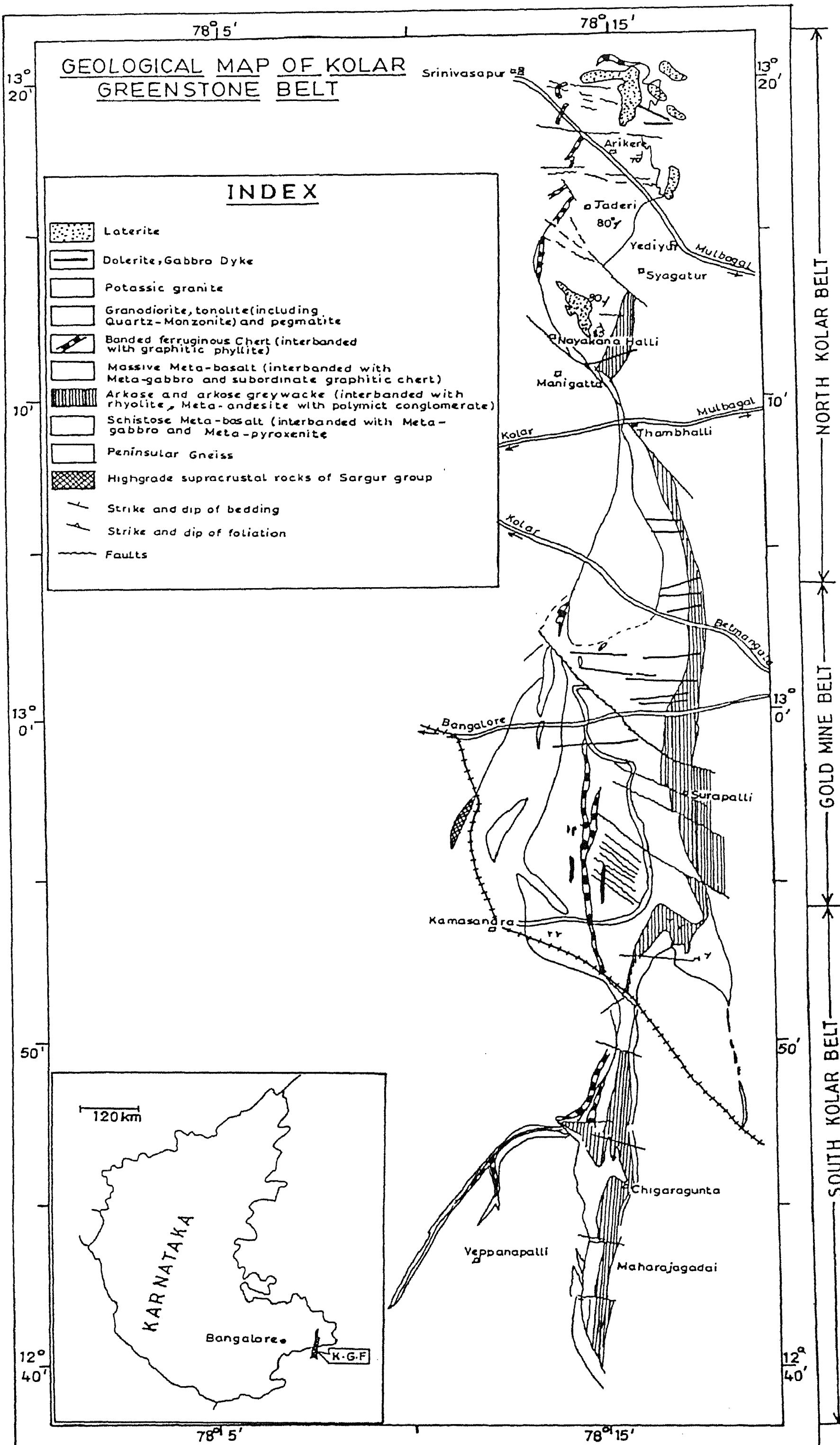

GEOLOGICAL MAP OF KOLAR GREENSTONE BELT
INDEX
Laterite
Dolerite, Gabbro Dyke
Potassic granite
Granodiorite, tonolite (including Quartz-Monzonite) and pegmatite
Banded ferruginous Chert (interbanded with graphitic phyllite)
Massive Meta-basalt (interbanded with Meta-gabbro and subordinate graphitic chert)
Arkose and arkose greywacke (interbanded with rhyolite, Meta-andesite with polymict conglomerate)
Schistose Meta-basalt (interbanded with Meta-gabbro and Meta-pyroxenite
Peninsular Gneiss
Highgrade supracrustal rocks of Sargur group
Strike and dip of bedding
Strike and dip of foliation
Faults
78° 5'
78° 15'
13° 20'
10'
13° 0'
50'
12° 40'
Srinivasapur
Arikere
Jaderi
Yediyur
Syagatur
Mulbagal
Nayakana Halli
Manigatta
Thambhalli
Kolar
Betmangala
Bangalore
Surapalli
Kamasandra
Chigaragunta
Veppanapalli
Maharajagadai
120 km
KARNATAKA
Bangalore
K.G.F
NORTH KOLAR BELT
GOLD MINE BELT
SOUTH KOLAR BELT

FIG. 4

1. Mafic unit:

The gold mineralisation in the Kolar Gold Field (KGF) is confined to metabasic rocks which were earlier described by Narayanaswamy et al (1959) and Ziauddin et al (1963) as tufted, granular, massive and schistose amphibolite representing metamorphosed pyroxenite, gabbro, basalt and andesite respectively (Fig.5). According to Subramanyam et al (1991) the metabasic rocks of KSB in general and the rocks of KGF in particular can be classified into pillowed komatiite metabasalt with or without spinifex texture, pillowed thoeliite metabasalt, Fe-enriched tholeiite, metabasalt with high alkali content and metagabbro. Well-developed schistosity in all rock types is seen close to shear zones.

Viswanathan (1974) first reported komatiite in Kolar Gold Field although Viswanatha and Ramakrishna (1980) contradicted the occurrence of komatiite. According to Rajamani (1986) important quartz carbonate gold lode occurs in the central massive tholeiitic amphibolite (the lode is generally referred to as amphibolite hosted auriferous quartz). However according to Subramanyam et al (1991) the important gold lode namely the Champion lode occurs in the komatiite metabasalt in the eastern side of Kolar Schist Belt. Subbaraman (1980) was the first to report that the Champion lode occurs within tufted amphibolite, which is now designated as komatiite. According to Rajamani et al (1985) both the komatiite and tholeiite have been derived by similar extents of melting of the mantle but at different depths, with komatiite having a deeper source. The significance of komatiite is that it might have played a possible role in supplying auriferous solutions. According to Viswanathan (1979) the komatiites are considered as principal carriers of gold from the upper mantle into the crust and therefore require identification of komatiites in the granite - greenstone belts of India to discover new gold deposits. However, clear relationship between the auriferous lodes and the komatiite has not been established. This aspect is discussed in detail in section 4 of Chapter 4.

In underground excavations of the Kolar Gold Mines the komatiite is seen as the invariable host rock for gold quartz lode of Champion lode and others of its type. On the other hand the tholeiite metabasalts are the host for the gold quartz sulphide lodes. The granular amphibolite to the west of komatiite is a Fe-rich metabasalt, whereas the metabasalt occurring in between McTaggart East and West lodes is a metagabbro (Fig.6). A thin but persistent band of tholeiitic metabasalt is seen along the KSB to the east of Champion gneiss. Amygdular and pillowed structures are commonly seen in all the members of mafic rock sequence. Mineralogically these mafic rocks consist of hornblende and plagioclase (oligoclase) with accessories like quartz, epidote, calcite, rutile and ilmenite. Metagabbros and metapyroxenites occur as lenticular, thin and discontinuous bodies. Gradations of one textural type into another perhaps indicate that the mafic group of rocks represents compositional flows, sills and intrusive sheets. Metabasalt (massive amphibolite) containing actinolite, albite, epidote and quartz is centrally located in the KSB more abundantly in the northern part.

2. Felsic unit (Champion gneiss)

This litho unit occurs along the eastern margin of KSB. At the northern end of the KSB (North of Nayakanahalli) this felsic unit is truncated by intrusive granite (Fig.4). It consists of grey to blue opalescent quartz and euhedral plates of plagioclase set in a matrix of schistose and gneissose quartz, feldspar and mica. In the southern part of the KSB, this felsic unit is coarse, inequigranular, strongly foliated with large granoblasts of plagioclase, aggregates of plagioclase, biotite, quartz and myrmekite. This Champion gneiss is believed to represent acid volcanics and tuffaceous rock. Very poorly sorted, immature polymict conglomerates occur as discontinuous bands within the Champion gneiss and this unit does not occupy any particular stratigraphic horizon (Mukherjee et al 1985)

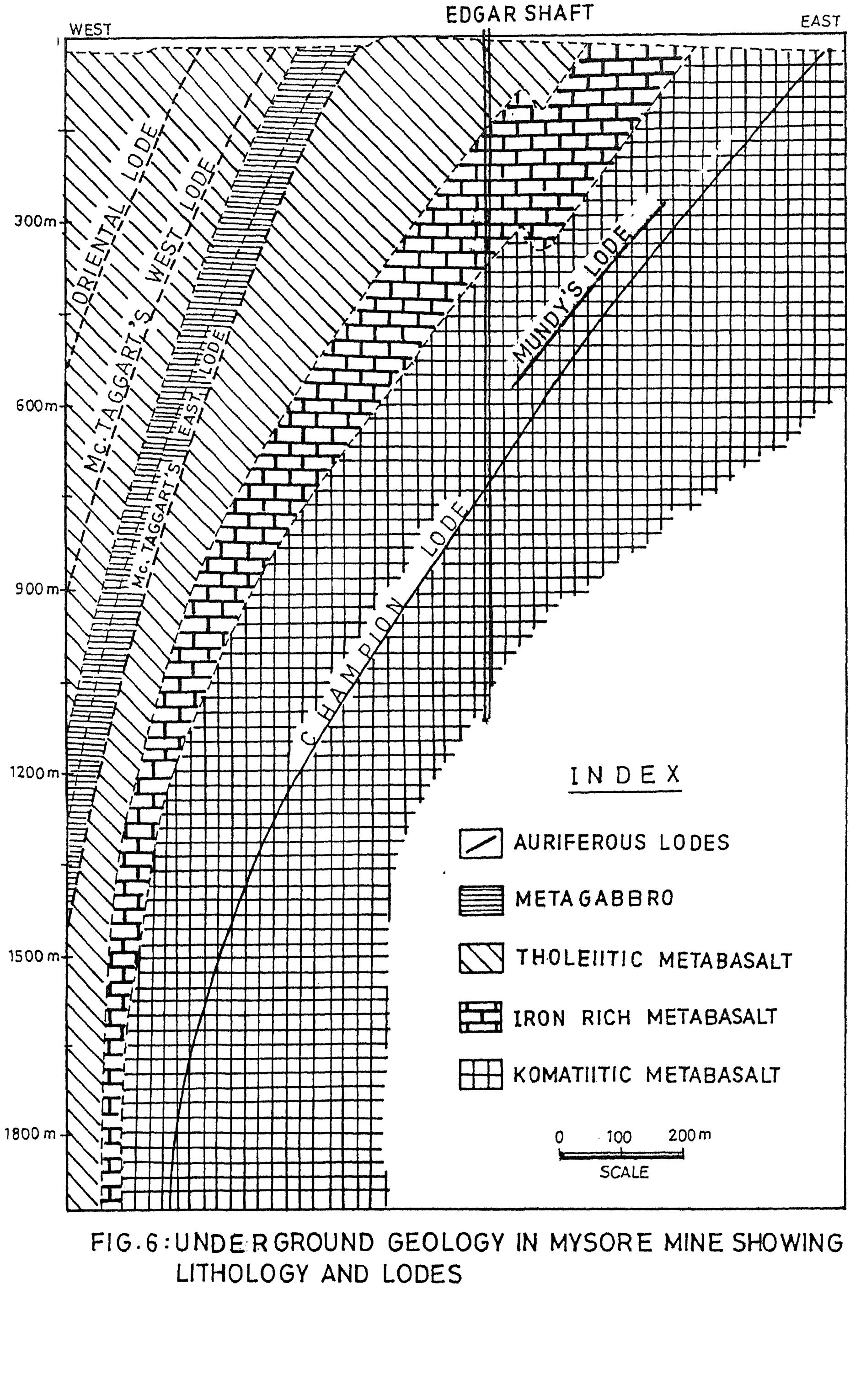


FIG. 6: UNDERGROUND GEOLOGY IN MYSORE MINE SHOWING LITHOLOGY AND LODES

3. Banded Iron Formation (BIF) and graphitic sulphide series

These constitute the least abundant rock types and are confined to mafic unit. These sedimentary formations are narrow (10 - 100 m wide). The BIF is heterogeneous and consists of quartz, grunerite and pyrrhotite. Wherever pyrrhotite is subordinate, this rock type grades into magnetite-quartzite. The graphitic sulphide schist consists of quartz, mica, amphibole and graphite with varying amounts of pyrite, pyrrhotite, chalcopyrite and sphalerite. According to Mukherjee et al (1985), the field relation suggests that the mafic unit (amphibole facies) with narrow intercalations of BIF and graphitic-sulphide schists appear to be the oldest units within the KSB. The felsic unit (Champion gneiss) along with polymict conglomerate appears to be the next unit. Both the mafic and felsic units are intruded by younger basic intrusives and gneissic rocks that are seen at the margins of the KSB. The general parallelism of foliation of gneisses with the schistosity of amphibolites, particularly near the contacts suggests a plutonic behaviour of gneissic rocks during tectonism (Mukherjee 1985). According to Krogstad (1989) the Kolar Schist Belt and the surrounding areas represent a "Suture Zone" where two gneisses and two amphibolite terranes with distinct histories were accreted.

4. Structure

Earlier workers Foote (1882), Narayanaswamy et al (1960), Nautiyal (1966), Srinivas and Srinivasan (1968), Swaminathan and Ramakrishna (1980) opined a synclinal structure for the schist belt. According to Mukherjee and Natarajan (1985), the rocks of this KSB have suffered a variable and polyphase folding deformation. The earliest folding (F1) identified at Mallappakonda in the southern part of schist belt appear to have produced E-W trending microscopic folds. Later movements produced N-S trending steeply doubly plunging tight upright fold (F2). Due to the later folding the KSB suffered bifurcation into narrow linear strips of synform with intervening antiforms being occupied by

gneisses and granites. This aspect is clearly seen in the southern part of KSB where there is no significant gold mineralisation.

The KSB is effected by predominantly NW-SE trending faults. The most significant of them are the Balaghat North Fault, the Mysore North and South Faults and Gifford's Fault system. These faults have displaced the gold quartz and gold quartz sulphide lodes.

5. Stratigraphy

The following is the stratigraphy of KSB as proposed by Viswanatha and Ramakrishna (1981) and modified by the author, so as to include all the formations of KSB.

Stratigraphy of the Kolar Schist Belt (modified after Viswanatha and Ramakrishna(1981)

	Recent	Laterite	
		Basic dykes	Dolerite,norite, diorite porphyry.
		Pegmatites	Quartz,Feldspar
		Gold lodes	Quartz veins with or without sulphides.
		Patna granite	Porphyritic, potassic
		Bisanatham granite	Diapiric tonalite to granodiorite.
		Gold Field volcanics	Metabasalt, basaltic andesite, pyroxenite and gabbro with iron stone and black shale.
DHARWAR SUPER GROUP (?)	KOLAR GROUP	Champion gneiss	Wackes,felsicvolcanics and pyroclastic rocks with ironstone and polymict conglomerate.
		Yerrakonda formation	Ironstone and graphitic schist with gabbro and pyroxenite.
		Kalahalli Amphibolite	Schistose and fissile amphibolite with pyro-xenite gabbro and iron-stone representing the metabasalt to the east of Champion gneiss.
		Peninsular gneiss	Migmatitic gneisses
		Ultramafic rocks, ironstone (locally manganiferous), veined calc-silicate rocks and veined mafic amphibolite	
	SARGUR GROUP	Mangan marble, cordierite-anthophyllite rock, cordierite – sillimanite - corundum quartzite and mica schist, fuchsite – quartzite	

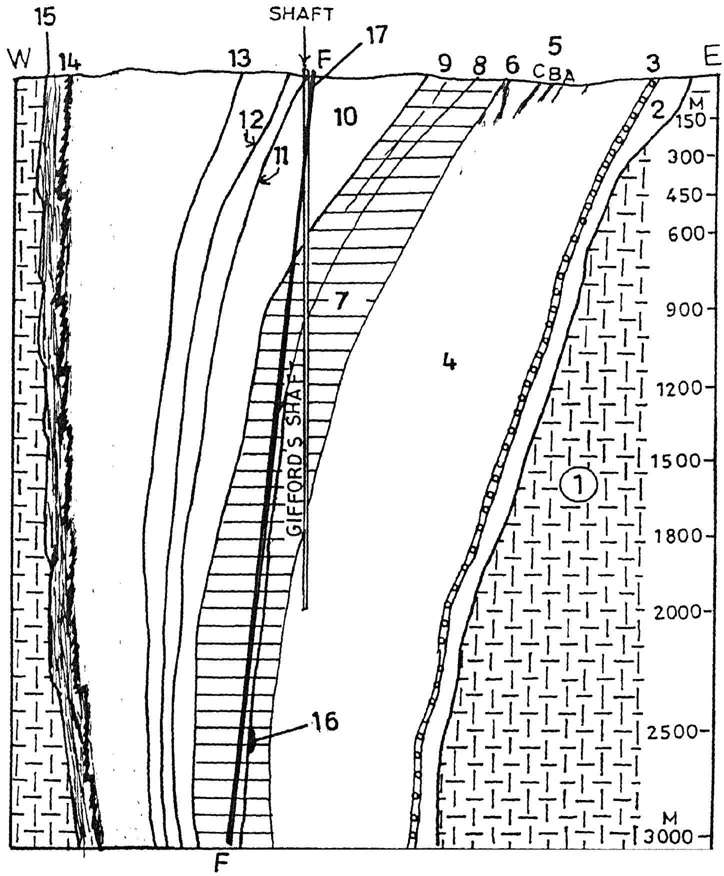
Base not seen

Geological details of the Kolar Schist Belt as seen across the Gifford's Shaft in Champion mine, from East to West: (Fig 7).

(1) At the eastern end of the Schist belt the Peninsular gneiss (1) is seen as basement.

(2) Further west a 100 m wide amphibolite is seen throughout the length of the Kolar Schist Belt. It is known as Kallahalli amphibolite (2), which is made up of schistose and fissile amphibolite. At places this formation contains well preserved pillow structures and enclose minor sheets of metagabbro (Viswanatha et al 1983). Because of its limited width and absence of any gold mineralisation, this formation has not been studied by many field geologists.

(3) To the immediate west of Kallahalli amphibolite is the famous Champion gneiss (3) which is fine-grained micaceous gneiss which extends throughout the 80 km length of the Kolar Schist Belt. It contains sheets and veins of granite, pegmatite and aplites. It is characterised by grains and blebs of opalescent blue quartz, which is commonly found in felsic volcanics and tuffs. Smeeth (1916) called this as Champion gneiss on the belief that it was responsible for gold mineralisation in Champion lode. The champion gneiss is closely associated with the Champion lode (Fig.8) at 6556' depth at the boundary of Champion and Mysore mines. The British mining engineers had named this gneiss as "dogger". The width of the Champion gneiss on surface varies from 300-800 m. The Champion gneiss was found to be auriferous at few places as per the exploration carried out by the Bharat Gold Mines Ltd., in the early 1980's at Surapalli to the east of Robertsonpet but the gold distribution was very poor and it did not persist for more than 5 m. depth.



1 - PENINSULAR GNEISS
2 - KALLAHALLI AMPHIBOLITE
3 - CHAMPION GNEISS
4 - SCHISTOSE AND GRANULAR AMPHIBOLITE
5 - MUSKOM LODES **A, B, C**
6 - DOLERITE DYKE
7 - KOMATIITE
8 - CHAMPION LODE
9 - MUNDY'S LODE
10 - MASSIVE AMPHIBOLITE
11 - Mc.TAGARTS EAST LODE
12 - Mc.TAGARTS WEST LODE
13 - ORIENTAL LODE
14 - BANDED IRON FORMATION
15 - WESTERN CONTACT OF AMPHIBOLITE
16 - PEGMATITE
17 - MYSORE NORTH FAULT

FIG-7: GEOLOGY AND DISTRIBUTION OF LODES IN KOLAR SCHIST BELT ACROSS GIFFORD'S SHAFT

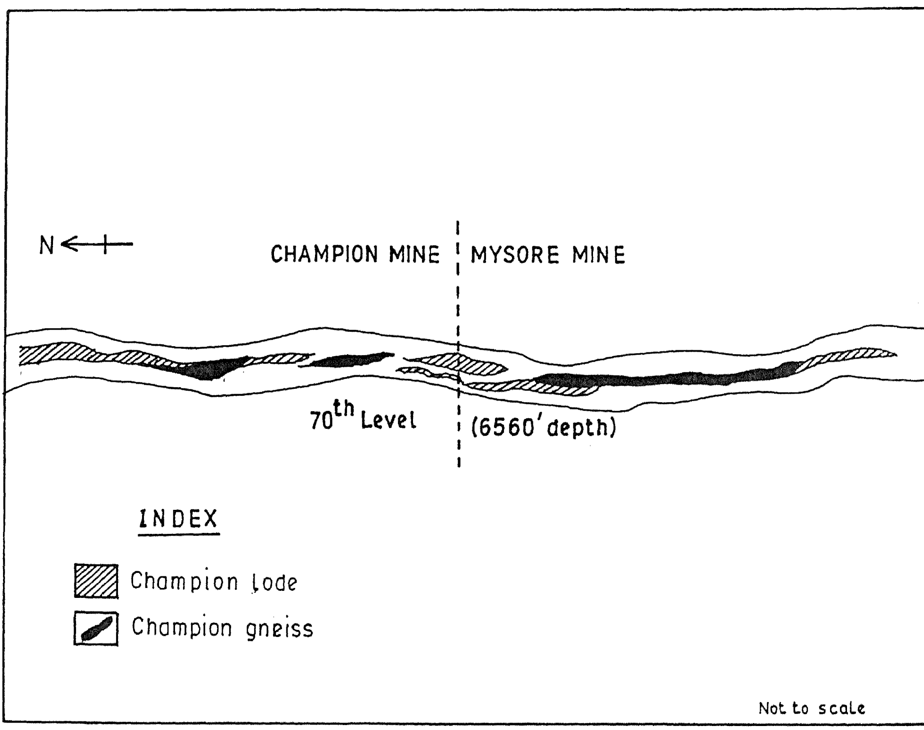


FIG.8: ASSOCIATION OF CHAMPION GNEISS WITH CHAMPION LODE

(4) To the west of the Champion gneiss the amphibolites are made up of schistose and granular varieties (No.4). This formation hosts the Muskum lodes, A, B and C (No.5) which have been tested for gold in the past and was found to be of no economic interest.

(5) Further west is a dolerite dyke of about 100' wide, which trend NNW. This dyke has been intersected in the Mysore mine workings (No.6).

(6) Further west is the typical komatiite (No.7) rock which hosts the Champion lode (No.8) and Mundy's lode (No.9).

(7) Further west is the massive amphibolite horizon (No.10) which hosts the three sulphidic lodes namely the McTaggart's east lode (11). The McTaggart's west lode (No.12) and the Oriental lode (No.13).

(8) Further west is the Banded Iron Formation - BIF (No.14) which is the least abundant and carries insignificant gold mineralisation. This formation grades from banded magnetite quartzite to a quartz - grunerite - pyrrhotite rock. The width of this formation varies from few meters to more than 100 meters. At places it is associated with graphite with varying amounts of pyrite, pyrrhotite, chalcopyrite and sphalerite.

(9) At the western end, the contact of the amphibolite (No.15) with peninsular gneiss is seen.

(10) Below 8000' depth the Champion lode is intruded by pegmatite (No.16).

(11) The Mysore North Fault (No.17) cuts through the rock formations diagonally.

The rock formations 1 - 13 dip towards west and only the BIF (No.14) appear to dip towards east. On the basis of this the earlier workers (Narayanaswamy, et al 1960) had suggested a synclinal structure for the rock formation of the Kolar Gold Field area.

Metamorphism

The main rocks of KSB have suffered regional, low-pressure amphibolite facies metamorphism as indicated by the mineral assemblages (Subramanyam et al 1991). It is seen that the amphibole facies rocks are wide spread in the northern and in the central part of KSB. The metamorphism gradually increases towards the margins as well as in the deeper structural levels in the south (Viswanatha and Ramakrishna 1981). On the basis of geochemistry, Narayanakutty and Anantha Iyer (1977) estimated 600°C at 3 to 5 K bars for critical mineral paragenesis.

Gold mineralisation

Gold mineralisation in the KSB is found in all the rock types i.e. mafic volcanics, the felsic volcanics, the BIF and graphitic schist. The KSB from the point of gold mineralisation can be divided into three belts (Fig.4).

(1) The Northern belt, a 40 km. long area lying to the north of Balaghat North Fault

(2) The Gold mine belt, a 10 km long area situated between Balaghat North Fault and Giffords fault wherein the entire gold mining activities during the last 120 years have taken place. This belt contains the Champion lode.

(3) The Southern belt, a 30 km long area lying to the South of Gifford Fault up to Maharajagadai in Tamil Nadu.

Since the 40 km long Northern Belt is devoid of any significant gold mineralisation, this area has been excluded from the present study.

The Gold mine belt hosts two types of gold mineralisation.

(a) Quartz hosted native gold in komatiite

(b) Sulphide and gold quartz which are associated within tholeiitic metabasalt and BIF

The 30 km long Southern belt has two types of gold mineralisation hosted in the following:

(a) BIF with gold in sulphides

(b) Gold in felsic volcanics and tholeiites.

Thus the gold mineralisation in the Gold mine belt and Southern belt can be classified into four principal types:

Type 1: Native gold in quartz veins hosted in komatiite

eg. Champion lode, Mundy's lode

Type2: Native gold in quartz at the contact of Champion gneiss with the tholeiite

eg. Old Bisanatham lode, Chigargunta lode

Type 3: Gold associated with sulphide hosted in theoliites

eg. McTaggart's East lode, McTaggart's West lode Oriental lode, and New Bisanatham lode

Type 4: Gold in BIF

eg. BIF along the western margins of KSB. i.e. Yerrakonda deposit, Mallappakonda deposit and other minor sulphide lodes along the western part of KSB.

While the types 1 and 2 are considered epigenetic in origin, the types 3 and 4 are considered as syngenetic (Rao and Reddy 1985.) For the present study the epigenetic type deposits are alone discussed.

A brief review of the ideas on the origin of various gold deposits in the world is as follows: -

Boyle (1950, 1955,1960) and Wanless (1960) have explained the yellow knife gold deposit in Canada as due to the mobilisation, migration and concentration of elements during regional metamorphic events involving granitisation. Anhaeussar et al (1969), Viljoen (1969, 1970) consider the gold deposits of Barberton mountain land in South Africa were initially present in the mafic and ultramafic lavas and were mobilised and concentrated in dilatent zones during metamorphic events attendant upon granite intrusion. Saager (1973) suggested that the source of gold in Swaziland greenstone belt is related to primitive peridotitic basaltic komatiite rather than to the intruding magma. According to Boyle (1965) other important gold deposits formed due to metamorphic secretion

Kalgoorli gold deposit, West Australia (Travis 1970)
Ashanthi deposit, Ghana, South Africa (Wilson 1971)
Kilomoto gold deposit, Zaire, Africa (Lavreau 1973)
Home Stock Dakota, USA (Swatin et al 1971, 1974)

The Champion lode with native gold in quartz is hosted in komatiite along with other metabasalts. It is difficult to classify the Champion lode into any one of the three theories i.e. (1) Abyssal (2) Magmatic hydrothermal and (3) Metamorphic secretion theories which are applied generally to gold mineralisation.

Atabek'yants (1981) and Subramanyam et al (1991) on the basis of geochemical studies noted that the Champion lode is of epigenetic hydrothermal origin.

CHAPTER-3

THE CHAMPION LODE

CHAPTER-3
THE CHAMPION LODE

The Champion lode is one of the 26 quartz lodes in the Kolar Gold Field area identified by Pryor (1923). Later Narayanaswamy (1960) listed 14 lodes on the basis of surface geological mapping carried out by the Geological Survey of India during 1954 - 1958. The distribution of these lodes is shown in Table-2 and in Fig.7. The Champion lode is the most important one from both economic and geological interest. This lode has been exploited for about 8 km length to a maximum depth of 3.2 km during the last 120 years. On the basis of ore shoot persistence, the Champion lode in the vertical section along the strike is a funnel shaped ore body.

Table – 2. The auriferous lodes of Kolar Gold Field

Eastern gold quartz lodes:
Vein type:

Quartz - carbonate lodes. Associated with eastern amphibolite comparatively rich lodes	1. Muscom lode A	} Present in schistose
	2. Muscom lode B	} amphibolite. Lodes are
	3. Muscom lode C	} of no economic value.
	4. Champion lode(high grade)}	
	5. Mundy's lode(low grade) }	Present in komatiite

Western sulphide bearing lodes:
Stratiform:

Rich in sulphides Interbedded with sulphide facies iron formation low grade.	6. McTaggart's East lode	}	1-2 g/t
	7. McTaggart's West lode	}	1-3 g/t
	8. Oriental lode (working)	} Present in	1-5 g/t
	9. New Sulphide lode A	}schistose or }	
	10. New Sulphide lode B	}massive }	very
	11. New Sulphide lode C	}amphibolite }	poor
	12. New Sulphide lode D	}	
	13. New Quartz lode E	}	
	14. New quartz lode F	} Present in komatiite(rich in silver)	

In the early part of 1880s when the geological controls of gold mineralisation were not properly understood by the earlier prospectors, the entire Kolar Gold Field area of about 16,000 acres was prospected by opening pits, trenches, winzes, etc., by about 40 British Mining Companies (Fig.9).

Ancient workings for gold in Kolar Gold Fields are evident on most of the 14 lodes. But the distribution, frequency and size of these workings indicate a general concentration on the Champion lode and to a lesser extent on the three sulphidic western lodes (Fig 9). The various lodes listed in Table-2 and shown in Fig.7 are subparallel which outcrop at an interval of 60 - 200 m across the strike (Narayanaswamy, 1960) and have been intermittently traced for 10 km along the strike. The eastern lodes (1-5) (Table 2) are quartz lodes where as the western lodes 6 - 14 are sulphidic lodes in general. The status of exploration and mining carried out on the various lodes up to 1987 is shown in Table 3.

The Champion lode is made up of quartz within a dark coloured country rock, which is a komatiite. This lode can be traced on surface for 5 miles (8 km) along the strike with many breaks in between (Fig.3) and has been followed to 10598 feet (3.2 km) depth where the Champion lode narrows to 300 m. Therefore in a vertical section along the strike the Champion lode appears as a funnel shaped ore body (Fig.10). The lode follows major foliations of the country rock. It is not a single lode but is made up of several impersistent quartz filled fractures, which are parallel or subparallel. Although this lode is striking N-S, at several places it exhibits pinching and swelling characteristics with dextral and synistral shifts (Narayanaswamy 1960). It also exhibits en echelon shifts, sharp kinks along the strike and dip, tight infra formational folds, horsetail fracturing and branching habits. These features along with other favourable factors have lead to the concentration of gold at structurally favourable sites.

TABLE - 3

Status of exploration and mining carried out upto 1987 on the different lodes in Kolar Gold Field area (compiled from BGML records)

Name of lode	Total Length covered by pits.trench (ft)	Total U/G develop-ment (ft)	Max. depth of develop ment (ft)	No. of Shafts sunk	No. of Boreholes drilled from surface	Surface Length of mine deve-lopment (ft)	Area
Eastern lodes:							
Muscom Lode	1000	2600	200	4	1		Robertsonpet
Pilot shaft lode	1000	1600	300	10	19		Mysore Mine
Balaghat lode	5000						Balaghat
New Bisanatham lode	1000	2000	400	3			Bisanatham
Champion lode	20000	32000	10598	35		26000	Kolar Gold Mines
Old Bisanatham lode	1000	3000		6	-	500	Bisanatham
Mundy's lode	1200	3000	1000	6	13		Champion Reef Mine
Western lodes:							
McTaggart's East	4700		200	1			Nundydroog Mine
McTaggart's West	15000	3000		3	20		-do-
Oriental lode	1500	10000	5000	4	12		-do-
Trial Shaft lode (A)	5000			1	1		-do-
Trial Shaft lode (B)	3200				5	200	-do-
New quartz lode E	4000	3000		5	26	3200	Champion Reef Mine
West Prospect lode	5600	1500	300		35		Mysore Mine
New Bisanatham lode	2600	2000	500	2	2	1000	Bisanatham
Wolf shaft lode		1200			1		Mysore Mine

The Champion lode varies in thickness from mere thin partings filled with quartz and calcite called "lode channel" to thick zones up to 15 m wide in folded zones. The average width of the lode is about 1 m only. Because of pinching and swelling characteristics of the lode, often barren patches or poorly mineralised zones are seen in between the branching of the quartz vein. The thick masses of quartz along folds are "zig zag" in habit, which were developed due to intersection of fractures. Such folded habit of the Champion lode is well exposed in the upper levels in the Nundydroog, Oorgaum, Champion and Mysore mines (Fig 11-A,B,C and D). These fold zones are sites of high gold concentration. Structurally they are not real folds as there are no changes in the foliation dip of the host rock and therefore these may be lode branches with interlinking fractures. This aspect is further discussed in the next chapter.

Description of the Champion lode along the strike: The vertical section of the Champion lode (Fig 10)along the strike i.e. North-South up to 3.2 km depth highlights the following geological features:

(1) The dark (black) colour represents the area mined out wherever the Champion lode was rich in gold content.

(2) The blank (white) areas represent either poorly mineralized zone or non-mineralised areas

(3) The horizontal lines represent depth for every 1000'

(3) The vertical lines represent the strike distance from North-South for every 1000'

(4) On the basis of mine development carried out during the last 120 years, the Champion lode is found to be a funnel shaped ore body.

(6) The Champion lode pitches towards North at 40° in the top levels and in deeper levels the pitch becomes steeper.

(7) The Mysore North Fault cuts through the Mysore and Champion mines and dips at 45° towards North up to 7000 feet depth and below which the fault is

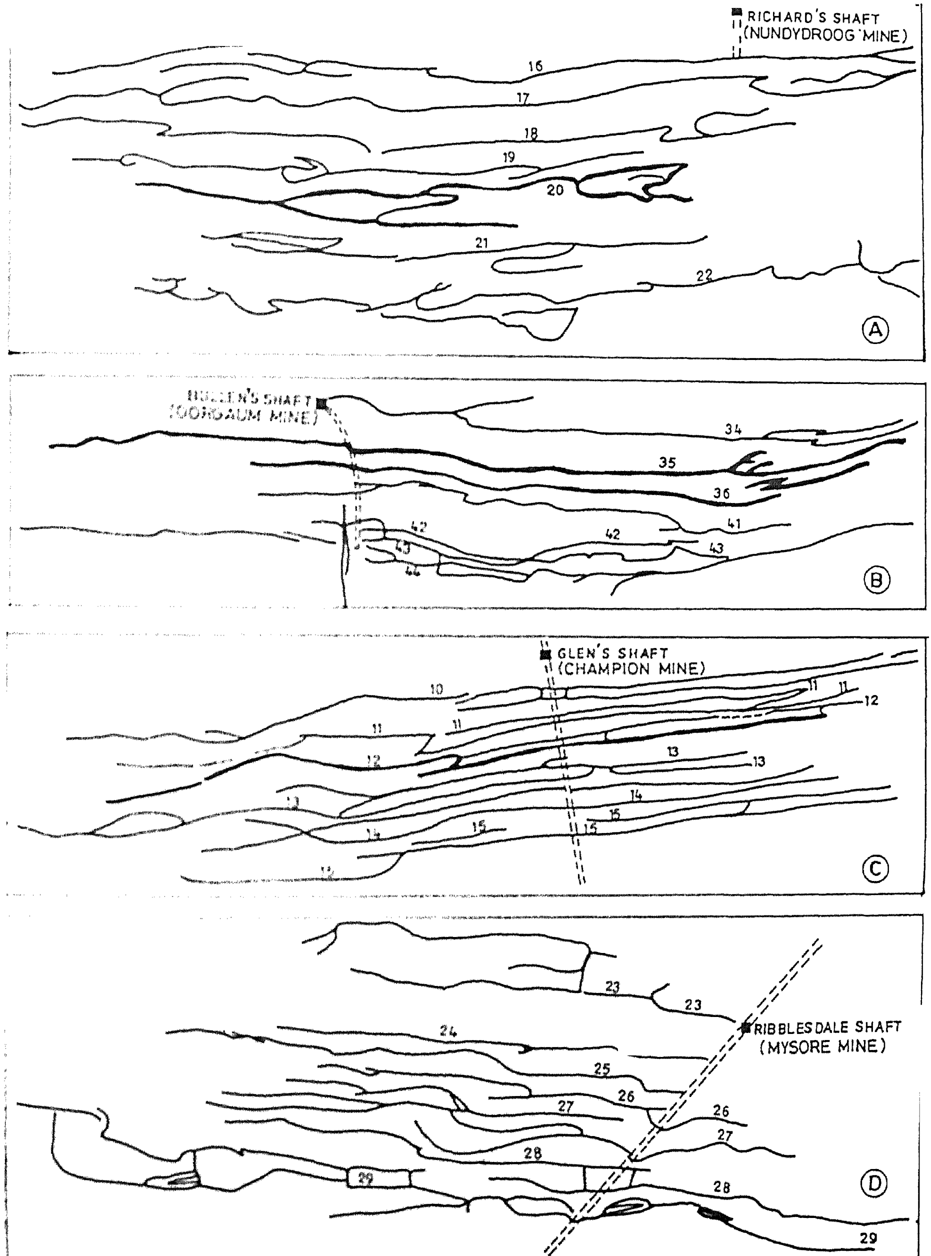


FIG-11: FOLD LIKE STRUCTURE IN CHAMPION LODE IN DIFFERENT MINES

deflected towards south and becomes almost vertical. This deflection of fault perhaps suggests a change of the physical characteristics of the rocks at depth.

(8) The Mysore North Fault has displaced the Champion lode vertically. Below 6000' depth the two ore shoots, which are separated by the fault, are given the names "The Glen ore shoot" on the South and "The Southern Ore body" on the North.

(9) The Mysore North Fault is generally considered as post mineralisation as there is no gold mineralisation in the fault zone.

(10) The Mysore North Fault appears to have displaced the Champion lode horizontall in the Mysore mine area as seen in Fig.5. Narayanaswamy (1960) has also noted the horizontal shifts by 400' - 500' of the rocks and the lode on surface along the Mysore North Fault.

(11) However, from surface to 3000 feet depth in the Mysore mine area two important ore shoots occur in the Mysore north fault zone which according to the author represent "fault drag shoots" (Fig.10). This aspect is further discussed in the next chapter.

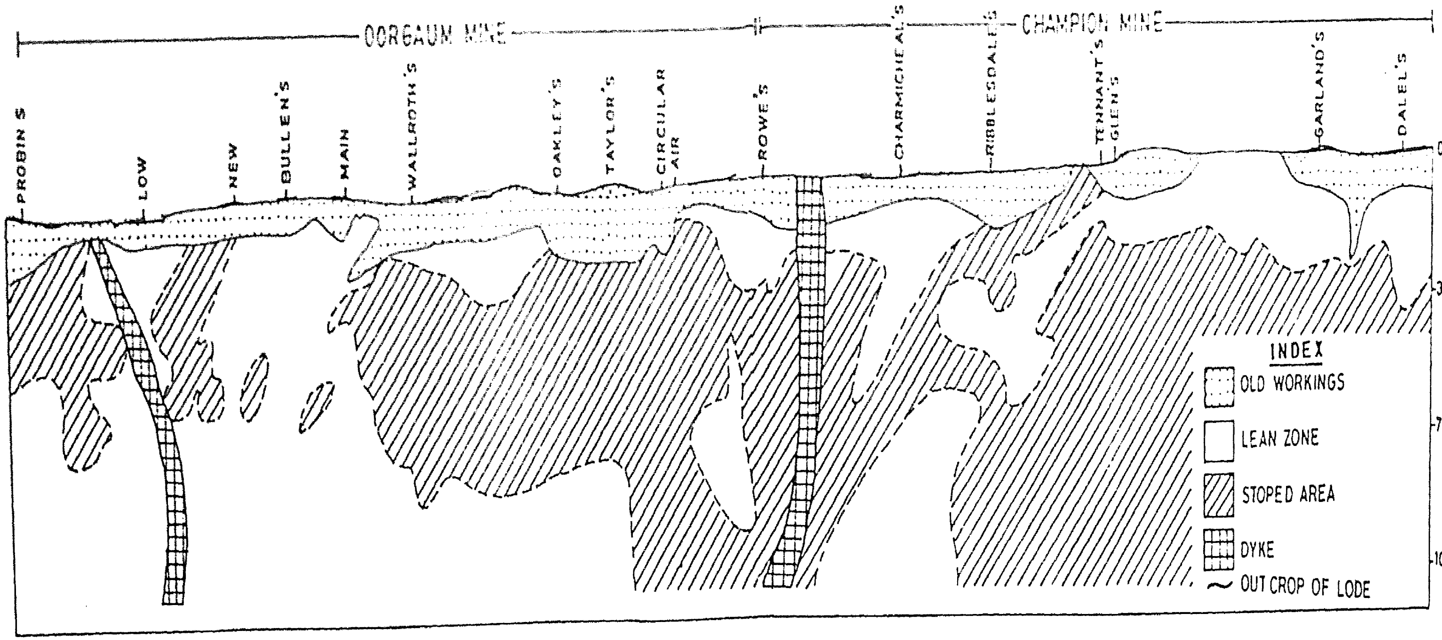
(12) Pegmatites occur in the central and northern parts of Kolar Gold Mines between 2000 to 9000 feet depth (Fig 10). The relationship of pegmatites to the quartz lode is discussed in Chapter 4.

(13) Five prominent dykes trending E-W are encountered in the underground workings, one in the Balaghat mine, two in Nundydroog, and one each in Oorgaum and Champion mines. All the five dykes dip steeply (Fig.10). While the dykes in Balaghat and Nundydroog mine dip towards south, the dyke in the Oorgaum and Champion mines dip towards north. There are no E-W dykes in the Mysore mine. The width of these dykes varies for 50 to 150 feet. According to Bichan (1947) the diabase dykes seen in Kolar Gold Mines are younger in age than other rock types. The dip of the dykes swerves as depth increases.

Like pegmatites, the dykes have also assimilated the rich portions of the Champion lode wherever they have intruded. Unlike the irregular occurrence of pegmatite, the dykes are more regular in their width and persistence in depth. The dykes exhibit chilled contacts at places where it has come in contact with the amphibolites and Champion lode. Because of lack of interest due to absence of gold, the dykes in the mines have not attracted the attention of geo-scientists. According to Radhakrishna (1994) Basaltic dyke rocks are particularly suited for palaeomagnetic studies since these rocks preserve in them the direction of the earth's magnetic field prevailing at the time of its consolidation. The dykes in the Nundydroog mines were studied by Reddy (1979) and Amitabha Sarkar and Mallik (1995). The thin section study has shown that these dykes are of dolerite type with plagioclase and pyroxene as chief constituents and iron oxide as minor constituent. In one of the dykes olivine has been noticed. In other section minor amounts of micropegmatite is noticed. In another section it is seen that pyroxene is altered to a lesser or greater extent due to dueteric effects. The alteration products are bluish- grey hornblende, biotite or chlorite. Iron oxide in the form of fine dust or specks is seen associated with alteration products.

(14) From a careful study of the Fig.10 it is observed that the dykes, pegmatites and the Mysore North Fault seem to converge towards the depth suggesting a common vent or neck, through which the quartz, gold, pegmatite and dykes have emerged. The Mysore North Fault also cuts through this vent.

(15) The old workings on the Champion lode as seen (Fig. 5) on the surface geological plan, are distributed throughout the 8 km length of the mine workings. The depth of the old workings range from few meters to more than 80 meters (Fig.12) suggesting that wherever the grade was high, the ancient prospectors have worked deep until they were not able to cope up with percolation of ground water. Below these old workings high gold values have been reported by the British Mining Companies during 1882 - 1900 in their annual reports.



FIG·12: SECTION OF OORGAUM AND CHAMPION MINES SHOWING DEPTH OF OLD WORKINGS

Mineralogy of Champion lode:

"Gold is characterised chemically by an extreme indifference to the action of all bodies usually met in nature".

-(J.K. Rose and WAC Newman 1937).

The Champion lode consists dominantly of quartz and some gold with other amphibole minerals in the form of caught up patches of amphibolite. The microfabric of the quartz in the Champion lode is characterised by marginal granulations on the larger elongated quartz grains. Varying amounts of irregular patches of amphibolite material caught up from the metabasic country rock komatiite show some interesting metasomatic mineralogical transformation (Subramanyam et al 1991).

The quartz makes up to more than 90%. The other accessory minerals include amphiboles, biotite, muscovite, tourmaline, apatite, scheelite, sulphides, Fe and Ti oxides and carbonate matter

Associated metals:

In the Champion lode gold occurs in native state with silver as a major associated metal. The fineness of gold at present is more than 900/1000, the other 100 parts is made up by silver, tungsten, copper, etc. From 1882 to 1934 the gold bullion of the Champion lode was 900/1000 fineness but during the subsequent years it has increased to 910 (Burdon 1948). Table No.4 indicate that in the upper levels the gold fineness was diluted by the extra amount of silver, scheelite and copper. According to Dixit (1980) the scheelite exhibits largely pneumatolitic replacement characters and it generally decreases with depth. This idea fits aptly to the widespread scheelite occurrence with 0.43% Wo_3 in the upper levels (up to 1000' depth) of the Champion lode and below which the scheelite occurrence

becomes negligible. According to Radhakrishna (1996) scheelite is also found in the Hutti Gold Mines with 5.30% Wo_3 between 1000 to 1500 ft. depth.

Table-4 :The fineness of gold produced during the last 100 years in the Kolar Gold Mines

Period	Fineness of gold in parts/1000	Source of ore
1882 - 1934	900 }	Champion lode100%
1834 - 1948	910 }	
1948 - 1958	930 }	
1958 - 1968	930 }	
1968 - 1972	930 }	Champion lode 80 %
1972 - 1978	920 }	Oriental lode 20 %
1978 - 1979	917 }	
1979 - 1980	927 }	
1980 - 1991	830	Oriental lode 80% Champion lode 20%

Ore mineralogy:

The Champion lode which tapers in depth represents the chief gold bearing quartz lode in the Kolar Gold Field and perhaps is the single largest gold concentration in a limited area any where in the world (approximately 8000 m x 1 m x 3200 m volume). The following ore minerals have been reported by Subramanyam et al (1991) is shown below.

Table – 5. Ore minerals associated with Champion lode

1 Sulphides/sulphosalts	:	pyrrhotite,chalcopyrite, pyrite, arsenopyrite, Galena, pentlandite (trace).
2. Native metals	:	Native gold, silver, copper, altite (Pb Te)
3. Oxides and tungstates		Ilmanite, anatase, scheelite
4.Others		Graphite

Nekrasov (1996) has listed about 40 gold bearing minerals depending on the maximum and minimum content of gold and other metals in the gold ores. Out of them the following four minerals may represent the natural alloys and intermetallic components of gold in the Champion lode (Table-6). This is based on fineness of gold and associated metals.

Table-6 Likely gold bearing minerals in Champion Lode

Name of Alloy	Metal	Min %	Max %	Density	colour
1. High purity gold	Au.	65	90	16.8 - 19.34	Yellow to light yellow
	Ag.	1	35		
2. Electrum	Au.	35	65	13.8 - 16.1	Light yellow
	Ag.	35	65		
3. Copper gold	Au.	78	98	19.1 - 18.6	Copper yellow
	Ag.	2	20		
	Cu.	20	2		
4. Gold	Au	60	98	18.0 - 19.1	Light yellow to white
	Hg.	1	20		
	Ag.	1	25		

The sulphide ore minerals mentioned in Table 5 are found only in the caught up patches of amphibolite in the Champion lode and they are not present in the quartz rich portions of the champion lode. The native gold distribution is restricted to the quartz only. The rich patches of Champion lode carry megascopically visible gold (>0.5 mm in size) and occasional nuggets weighing more than hundreds of grams of gold. Native gold occurs as minute inclusions (5 - 25μ) within the quartz grains. Several rare tellurides and other gold bearing alloys which have been reported by other workers is listed below

Table-7. Tellurides and other gold bearing alloys reported from Champion lode (Suubramanyam et al 1991)

1. Gold tellurides :	Rozkhov 1966
2. Dumertite and wollastonite :	R.W. Boyle (1979)
3. Ulmanite	
Tetrahedrite	
Hawleyite	Genkin (1981)
Tzumoite	Safonov (1984) Volynskyte
4. Cotunnite	
Pb Teg Cl_4S_2	Sofonov (1984)
Pb Te Cl_8	

Wall rock alteration:

> *"A study of changes in rocks contiguous to ore bearing fissures is essential to a thorough understanding of the genesis of such deposits"*
>
> **-(W. Lindgren 1981).**

Generally the Champion lode, a light coloured quartz lode is in contact with the enclosing dark coloured country rock, which is komatiite. This aspect was well-understood even 100 years ago itself by the illiterate miners while sampling the Champion lode. A zone of alteration is clearly seen for a distance of 2 - 3 meters on either side of the lode bringing the following changes (Subramanyam et al 1991)

1. Epidotisation of amphibolite and feldspars
2. Biotitisation of amphiboles and development of alkali feldspars.
3. Diopsidisation of amphiboles
4. Tourmalinisation
5. Muscovitisation and sericitisation
6. Development of sphene and scheelite
7. Development of apatite

Extent of mine development on Champion lode:

For exploitation of the Champion lode up to a maximum depth of 3.2 km, the following lengths of tunnels, shafts, and winzes have been excavated from 1880 to 1980.

(1) winzes and drives : 100 km (1875 - 1880)

(2) Shafts and winzes : 64 km } (1880 – 1980)

(3) Cross cuts and drives : 839 km }

Total : 1003 km

Other important activities connected with the mine development on Champion lode are furnished in Table-8 (Gupta 1980)

Faults:

Three main systems of post mineralisation faults have affected the rocks of the schist belt and the Champion lode (Narayanaswamy et al 1960). Out of them NNW - SSE to NE - SW trending faults are the most important ones which lie roughly parallel to the axis of cross folds. The following are the important faults encountered in the mining area.

(1) Balaghat North Fault

(2) Tennant's Fault

(3) Mysore North Fault

(4) Mysore South Fault

(5) Gifford's Fault

Table - 8

Important events connectd with the mine development of Kolar Gold Mines

Decade	Ore production in lash tonnes	Gold recovered in Kgs.	Grade G/t	Labour (Nos.)	Remarks
Prior to 1880	3.3	6200	18.5	20000	40 mining companies worked in KGF area.
1881-1890	1.3	6200	47.5	22000	Important surface shafts were sunk
1891-1900	1.5	8900	41.9	22500	Metallurgical plants were installed.
1901-1910	61.0	170800	28.0	34000	Electric power was made avaialable.
1911.1920	69.0	125480	18.19	23000	Rock pressure and Temperature problems increased
1921-1930	59.5	116980	19.6	17000	Balaghat mine was closed.
1931-1940	64.4	116980	15.4	27000	Surface Air Cooling plants were installed.
1941-1950	51.0	63340	12.43	24000	Depletion of high grade ore and decline in mining activities.
1951-1960	52.9	54125	10.23	22000	Nationalisation of gold mines by the state govt.
1961-1970	45.1	32450	7.15	13200	Gold mines taken over by govt. of India
1971-1980	36.2	19400	5.35	13200	Gold mines made public sector undertaking. Old gold mines at Ramagiri, Bisanatham, Chigargunta revived.
1981-1990	22.2	11700	3.98	12000	Deep workings abandoned.
1991-1998	19.5	5446	2.8	5000	flooding of the mines below 3000' depth.

Remarks: During 1997-98 the sources of ore was as follows:

(A) From KGF Area
- (1) Champion load 20,000 tonnes
- (2) Oriental lode 70,000 tonnes

90,000 tonnes

(B) Outside KGF [from AP]
- (1) Chigargunta 40,000 tonnes
- (2) Ramagiri 13,000 tonnes
- (3) Bisanatham 7,000 tonnes

60,000 tonnes

Total of (A) + (B) = 1,50,000 tonnes of ore @ 3.25 g/t.
The labour strenth was 4300.

All these faults are shown in the surface map (Fig.5). The Balaghat North Fault is not shown in the section (Fig.10) because it occurs further north of the Balaghat mine. Similarly the Tennant's Fault, Mysore South Fault and Gifford's Faults are also not shown in the section because their effect on the Champion lode is very minimal. The Mysore North Fault (Fig.3) is the only major fault, which has considerable effect on the Champion lode and is shown in the section. All the faults are post mineralisation in age. This is very well seen both on the surface and underground in the Mysore mine area where the Champion lode has suffered a lateral shift towards east. Subbaraman (1980) who mapped the underground workings of Mysore mine has brought out this aspect very clearly (Fig.13). Mysore North Fault is further discussed in Chapter 4.

Some General features of the Champion lode:

1. Although more than 1000 km of underground tunnels have been excavated nearly 400 km of them may be on barren country rock to provide access to the ore body.

2. Gold distribution in Champion lode is highly erratic. However there are some spots throughout the length and depth of the mines where gold values are very high giving rise to "Nugget effect" (gold values of 50 g/t more). This aspect is discussed in greater detail in the next chapter.

3. The economically significant length of the Champion lode is restricted between the Balaghat North Fault in the north and Gifford's Fault in the south. These faults can be seen on the surface map (Fig.5) but not represented in the strike section (Fig.10).

4. The komatiite is a high Mg. amphibolite and hosts the Champion lode up to 1200 m depth as observed in the Mysore mine and below this depth the

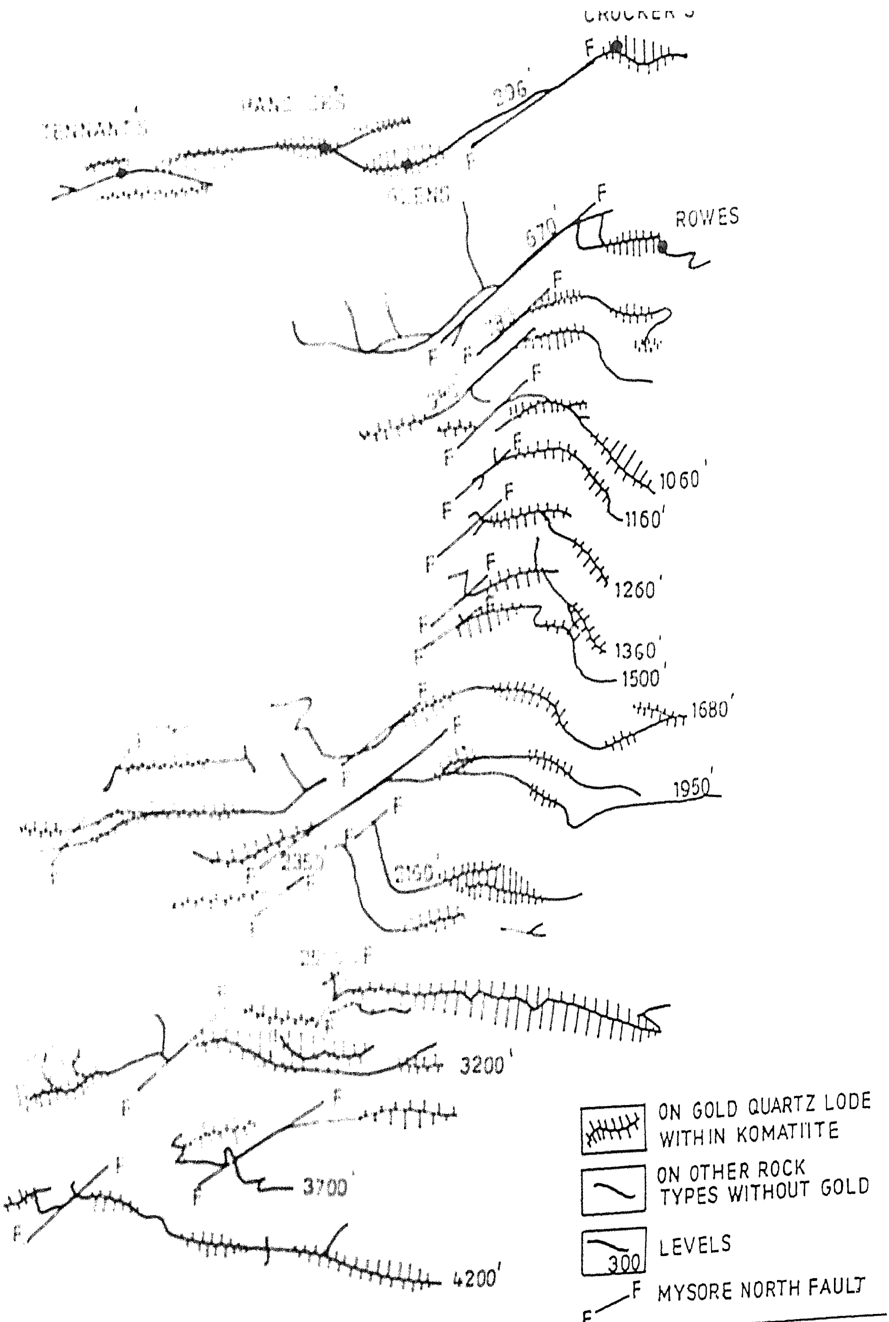


FIG.13 UNDERGROUND GEOLOGICAL MAP OF CROCKER'S SHAFT AREA, MYSORE MINE

komatiite becomes fine grained (Subbaraman 1980). This aspect has also been reported by Subramanyam (1991)

5. Gold mineralisation in the Champion lode and other lodes is pre-faulting according to earlier workers including the author who carried out detailed underground mapping in 1978. However Subramanyam et al (1991) think the gold mineralisation is post faulting.

6. Although in the area south of Mysore mines, the komatiite and quartz veins continue, there is no gold mineralisation. North of the Balaghat mine the Champion lode abruptly ends at the Balaghat fault, and the lode and komatiite have not been traced on the northern side of the fault.

7. In the weathered zone (from surface to about 80 m depth) there was considerable concentration of gold due to secondary enrichment in the oxidised zone yielding more than 40 g/t (Gupta 1980).

8. Although the komatiite is the host rock for the Champion lode, generally it is considered that there is no evidence to show that the komatiite is the source rock for gold. However, evidence for the komatiite as the source for gold is presented in the next chapter.

9. The search for the placer gold in and around the Kolar Schist Belt has not yielded any useful information (Ramakrishna 1980)

10. The Champion lode has genetic characters similar to other gold deposits in the greenstone belts in South Africa, Canada, W. Australia and U.S.A. (Ziauddin et al 1974).

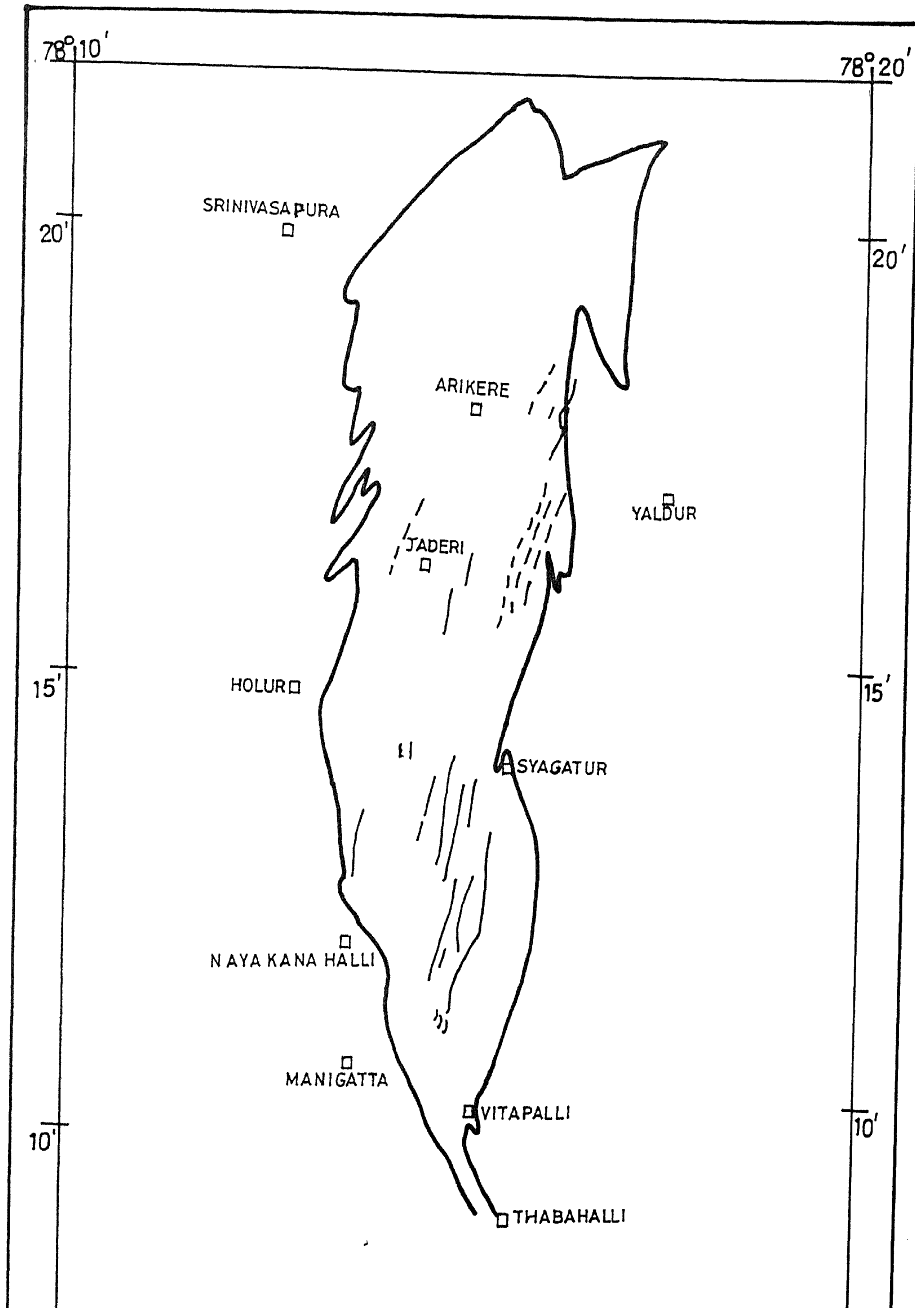
11. Temperature and pressure gradient studies carried out in Kolar Gold Mines on the Champion lode workings do not conform to the theoritical assumptions. Further details are discussed in Chapter 4.

12. To trace the Champion lode or any similar type of gold mineralisation in the area north of Balaghat Fault, the Geological Survey of India carried out integrated surveys consisting of geological, geophysical, geochemical and drilling, etc. These surveys picked up impersistent quartz veins of very poor gold values (R. Gokul, 1980), (GSI report 1981) Fig.14.

13. During 1981-83 a geostatistical evaluation of the mine data of Champion lode was carried out to locate blind ore bodies in the mines under a Science & Technology scheme by three group of Scientists attached to (1) I.I.T., Kharagpur (Prof. S.V.L.N. Rao), and Presidency College, Calcutta (A.K. Saha), (2) National Geophysical Research Institute (Dr. D.D. Sarma) and (3) CSIR, New Delhi (Dr.A. Ghosal). Since this exercise was carried out in total isolation of basic geological inputs, the results were totally disappointing (A.K. Saha, SVLN Rao and Shankar Sen -May 1983), D.D. Sarma (May 1983) and A. Ghosal (May 1983).

14. Under a United Nations Development Project (UN/DTCD Project IND/82/014) during 1984-1986, several geoscientists from various countries visited the Kolar Gold Mines to suggest ways and means of improving the over all performance of Kolar Gold Mines in the field of gold exploration and metallurgy. Even these experts also could not give any new ideas. [A.G.Royle (July 1984), S.V. Grigorian (Sept.1984), I.S. Parrish (1984, 1985), V.K.S. Varadan (February 1985), R.W. Boyle (May 1985), J.L. Evans (December 1985)].

15. Since 1992 the Champion lode mine workings in all the mines is water logged after the Government of India decided to phase out the mining operations for



FIG·14: MAP OF NORTH KOLAR SCHIST BELT SHOWING IMPERSISTENT QUARTZ VEINS OF NO ECONOMIC VALUE

uneconomic reasons. However, to keep the mine workers engaged the management reopened some levels up to 500' depth to mine the low grade Footwall branches of the Champion lode in the Mysore mine (Hancocks shaft area) and in the Champion mines (Glen shaft area) which yielded only about 2 - 3 g/t. These shallow workings also have been abandoned from 1.5.99 for uneconomic reasons. This marks the end of 120 years of mining activity on the Champion lode.

16. The mine workings in the Nundydroog mine since 1949 are being carried out on Oriental lode (a sulphidic gold quartz lode) as the Champion lode petered out at 9000' depth. The Oriental lode is yielding about 4 g/t and the present mining activity is restricted up to 1000 m depth below which the mine is water logged.

17. During 1981-89, the scheelite (+ 65% Wo_3 grade) that was present in the mill tailings around Walkers Shaft in Nundydroog mine was successfully recovered as a part of diversification of gold mining activities. During this 8 year period about 2,03,507 tonnes of tailings were treated and 106.6 tonnes of sheeelite was recovered.

18. Since 1986 the gold available in the mill tailings (about 0.8 g/t) is being partly recovered by heap leaching technology. During the last 12 years (up to 1997-98) about 4 lakh tonnes of tailings have been treated from which 330 kg of gold has been recovered.

19 In order to survive the Bharat Gold Mines Ltd., an undertaking of Government of India under the Ministry of Mines, has diversified its gold mining activities outside the Kolar Gold Mine in Andhra Pradesh state at Chigargunta and Bisanatham in Chittoor district and at Ramagiri in Anantapur district. This has yielded nearly 400 Kg of gold per year. From 1-8-99 the Ramagiri mine has also been closed temporarily for administrative reasons

20. In order to find (if any) missed patches of Champion lode left by the ancient people, the Management of Kolar Gold Mines carried out "Crown-Pillar exploration" during 1997-'98 in the Mysore mine area between the Tennants shaft and McTaggart's incline shaft, south of Mysore North Fault over a distance of about 500 meters. The exploration consisted of drilling a series of shallow boreholes up to 60 meter depth to locate any crown pillars of Champion lode and its 3 branches. This exercise also did not yield any anticipated results. Perhaps the ancient miners were too shrewd in not leaving behind pillars of Campion lode, which was of high grade.

CHAPTER-4

FACTORS OF GOLD CONCENTRATION

CHAPTER-4

FACTORS OF GOLD CONCENTRATION

The occurrence of the Champion lode, it's structures, associated fractures, the country rock enclosing the lode and the igneous intrusions have all probably influenced the localisation of the gold where it is. Some of the factors that are considered responsible for the localisation of ore are:

(1) Shape of the ore body,
(2) Vent of the ore body
(3) Host rock and Source rock
(4) Various types of fracturing of ore body
(5) Caught up ore shoots
(6) Microfracturing and nugget formation
(7) Reduced temperature and pressure of the host rocks towards the surface
(8) Intrusion of pegmatites and
(9) Weathering of the ore body.

These nine factors are considered as important and have influenced the concentration of gold. These aspects are discussed in detail.

4.1. Shape of the ore body

The Champion lode is roughly a funnel shaped ore body. The surface of Kolar Gold Field area is dotted by a number of ancient old workings and shafts over a length of 26250 feet (8000 m). The breaks in the continuity of the Champion lode both along the strike as well as along depth is characteristically displayed by the discontinuous distribution of the ancient as well as modern

workings (Fig.5). At about 200' depth (Fig.10) the discontinuity of the Champion lode becomes very pronounced with varying length of gaps in mineralisation. At deeper levels the length of the Champion lode gradually becomes lesser and at 10,500' depth the Champion lode is less than 1500' long (Fig.10). The Table-9 shows the decreasing length of the Champion lode at every 1000' depth.

Table-9 Length of Champion lode at different depths

Depth (in feet)	Length of Champion lode (in feet)	Averagelength (in feet)
Surface	26,250 (8000 m)	}
1000	26,000	}
2000	24,000	} Upper part
3000	24,000	} 23000
4000	20,000	} (7010 m = 7 km)
5000 (1524 m)	18,000 (5486 m)	}
6000	17,000	}
7000	14,000	}
8000	7,000	} Lower part
9000	6,000	} 7915
10000	2,000	} (2412 m) = 2.4 km)
10500 (3200m)	1,500 (457m)	}

Note: The total length includes the intervening gaps in stoping operations, which may represent non-ore zone or very poorly mineralised zones; and intrusion of pegmatites and dykes.

From the above table it is clear that from surface to 7000' depth, the length of the Champion lode gets reduced gradually. Between 7000' and 8000' depth there is an abrupt and drastic reduction in the length. Between 8000-9000' depth, the length of the lode gets further reduced gradually. Below 9000' depth and up to or depth of 10500' there is again a sharp reduction in the length. This explains the tapering nature of the Champion ore body with depth (Fig. 10).

Now, it is clear that the average length of the Champion lode in the upper levels (surface to 5000' depth) is 23000' whereas in the lower levels (5000' to 10,500' depth) the average length is only 7915'. This additional strike length of nearly 15000' in the upper levels is a major geological factor that has contributed to greater availability of gold in the upper levels.

A closer examination of the vertical section (Fig.10) will reveal that the Champion lode is really asymmetrically funnel shaped. The northern outline is badly disturbed due to intrusion of pegmatite, perhaps very productive portions of the Champion lode below 5000' depth have been assimilated by pegmatite leading to loss of valuable gold.

In this vertical section the Champion lode has a narrow vent below about 6000' depth constituting of the Glen ore shoot and the southern ore body, which ore separated by Mysore North Fault .

Whether the Champion lode ore body was originally a funnel shaped one or that it attained this shape due to intrusion of Pegmatites is not clear. The intrusion of Pegmatite in the southern part i.e. in the Champion and Mysore mines is very negligible. The northern part i.e. in the Oorgaum, Nundydroog and Balaghat mines, the occurrence of Pegmatite is considerable with much of it at deeper levels. The shape and nature of occurrence of these pegmatites is such that they may not have influenced the shape of the ore body very much. It is probable that the original shape of the ore body was in the form of a crude funnel into which pegmatites have intruded along the available weak planes and disturbed the symmetry of the funnel shape.

4.2.Vent of ore body

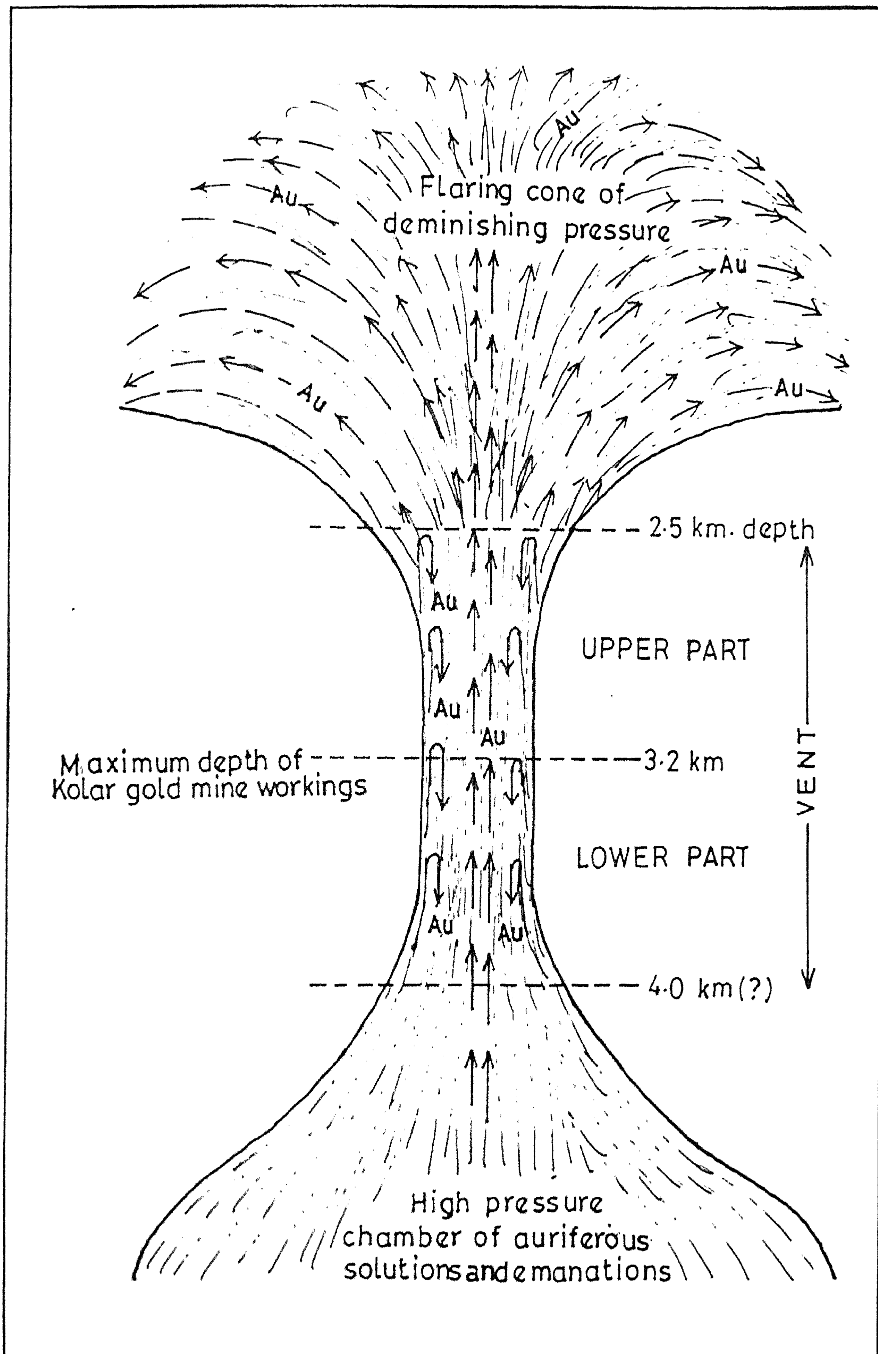
In the previous section it was shown that the champion lode has a crude funnel shaped structure. The deeper parts of the centrally located Oorgaum and

Champion mines extend deep and form a narrow neck-like portion consisting of the lode below 6000' depth. This neck-like portion is called the vent. It may be possible that the ore fluids migrated upwards through this neck or vent to form the Champion lode. The ascending fluids had to fight against the confined pressures before migrating upwards into favourable fractures for the deposition of gold. During this process the invading auriferous fluids gave rise to a new set of microfractures which also became loci for gold deposition. During the waning periods of gold migration and concentration into the Champion lode, the pressure in the fluid chamber was perhaps reduced greatly, as a result, the gold bearing solutions could move upwards rather sluggishly resulting in the collapsing and slumping of solutions into the neck it self. Due to repeated collapsing of the auriferous solutions, the neck/vent of the chamber got enriched by progressive addition of gold (Fig.15).

This is clearly illustrated in the mine sections by the distribution of high gold values in the southern ore body and Glen ore shoots (below 6500' depth) both of which represent the upper part of the vent as can be seen in fig. 16. This vent of the ore body was later cut by the Mysore North Fault giving rise to two independent ore shoots namely South ore body and Glen ore shoot (Fig.17). Normally the ore shoots die in depth with depleting values. However, the southern ore body and Glen ore shoot retain high gold values because of their origin in the vent. This aspect of the Glen ore shoot is depicted between 6500' to 10500' depth in Fig.18. Thus the southern ore body and Glen ore shoot which represented the vent of the Champion lode show higher average gold values than in the upper levels of the funnel portion.

4.3. Fracturing

The concept that no ore deposition can take place in solid rocks without fractures is a universally accepted theory. Fractures form channel ways for solutions and act as receptacles for ore deposition. In mineral vein formations,



FIG·15: IDEALISED SECTION OF THE VENT OF THE CHAMPIAN LODE

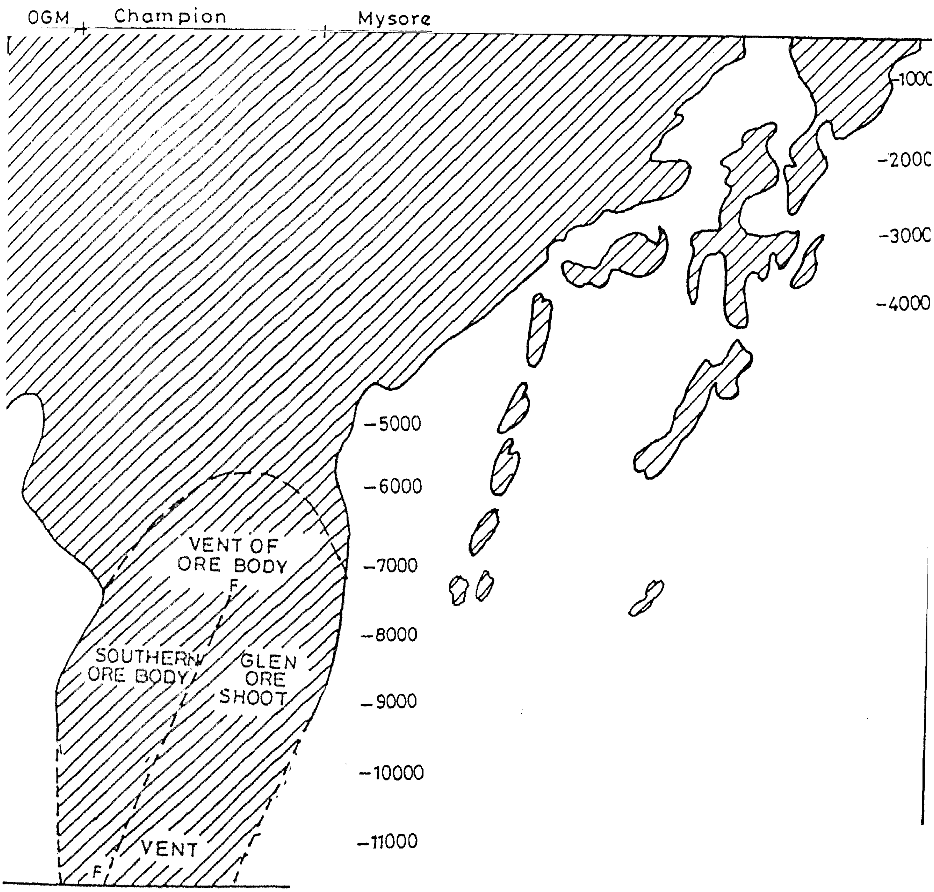


FIG.16: UPPER PART OF THE VENT OF ORE BODY BEFORE IT WAS CUT BY MYSORE NORTH FAULT

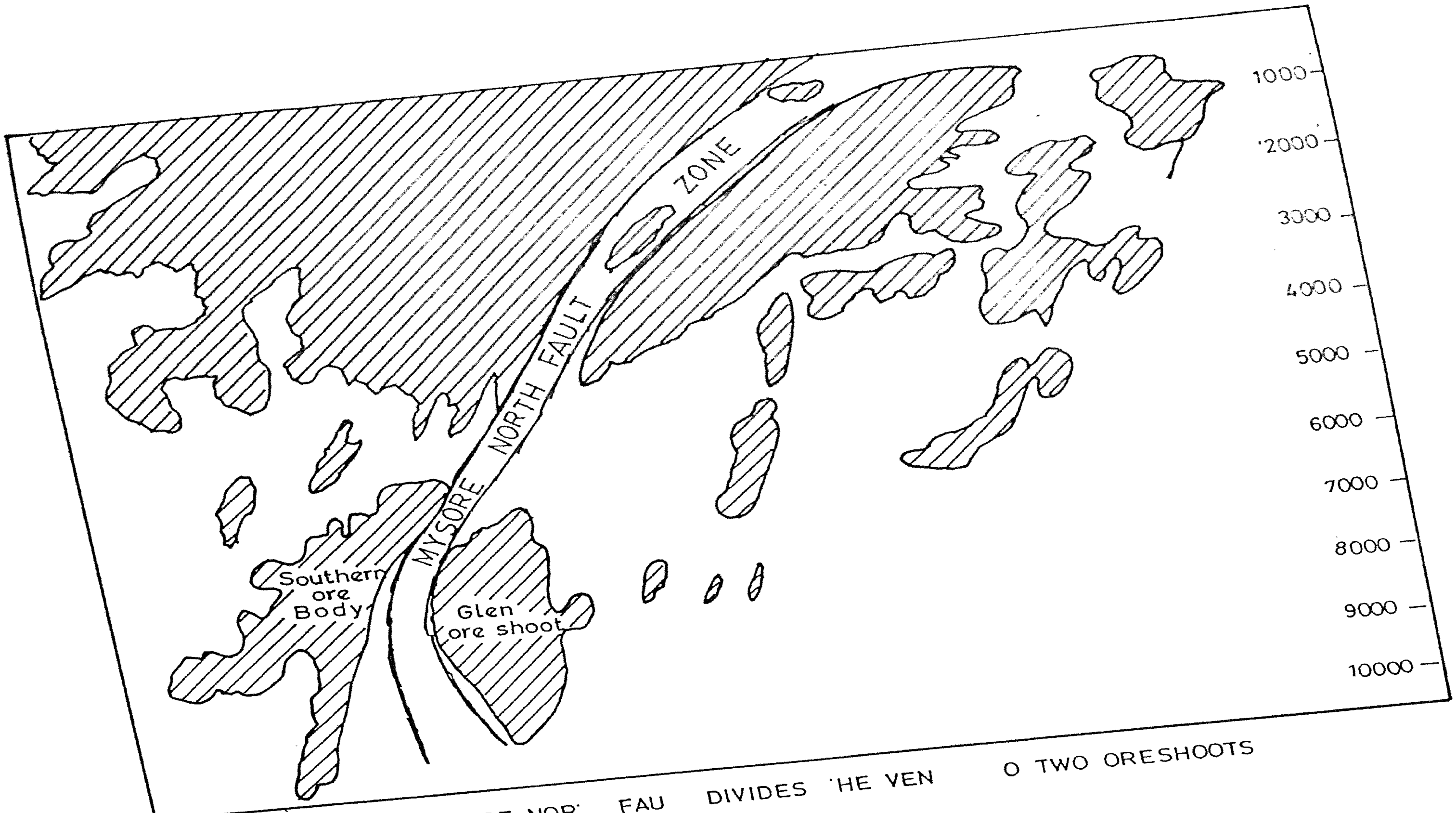
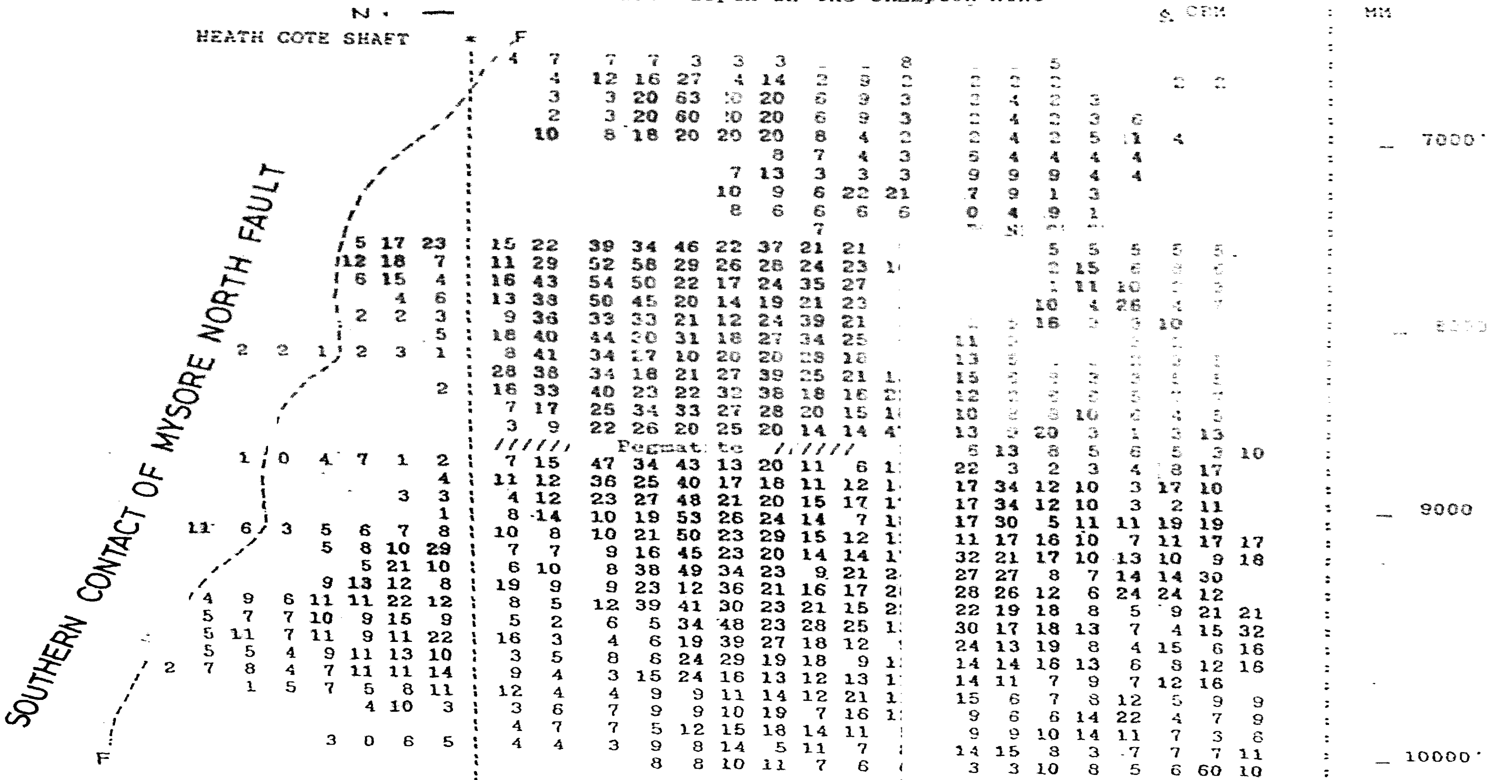


FIG HE MYSORE NOR' FAU DIVIDES 'HE VEN O TWO ORESHOOTS

FIG. Showing gh old values in the vent represented by the Glen o e shoot between 500' to 10100' depth in the Champion Mine



Note MN
Figure indicate go value in grams per ton f ore
Mysore North Fault
Mine boundary between Champ on and Mysore
Pegmatite intrusion.

the fractures are the most dominant controls, which decide the size and shape of ore body.

Basically the fractures are the manifestations within the competent rocks due to tectonic forces which act from within the earth but towards the surface.

Depending upon the nature of rock, the type of tectonic forces, fractures can be classified into singular, multiple, en echelon, curved both along the strike and in depth, horse-tail branching, overlapping, intersecting, pinching and swelling, low angle fracture, etc.

Gold mineralisation has taken place at certain structurally controlled favourable locations within Champion lode. According to Bichan (1947) "the localisation of ore shoots in Kolar Gold Field present one of the clearest and most excellent example of the influence of structural control in the formation of important bodies of gold bearing ore material. The grade of the ore may be ascribed to the co-incidence of large scale regional shearing to admit mineralising fluids containing gold concentrates from the magma through differentiation".

For the present work, the following structural features have been identified as causative factors for high incidence of gold. These features have been identified, analysed and discussed with actual case studies encountered in the Champion lode.

4.3.1 Earth's Gravity as a factor for concentration of gold along the footwall of the lode

As an outcome of the Newton's theory of gravitation, we have "weight" as a property of matter, which imparts a body the tendency to fall towards the earth. This Principle can also be applied in describing the early magmatic segregation of heavy minerals by gravitation in a magma chamber.

In the gold mineralisation process, the ore bearing solutions and emanations are carried upwards from the ore chambers and the gold gets deposited in structurally favourable sites such as fractures, fissures, etc. In the low angle dipping fractures as seen in the upper levels of Champion lode, the gold bearing solutions may have moved upwards along the hangingwall contact. But because of gravitational pull, the gold which has a high specific gravity (sp.gr. of Pure gold - 19.3), soon drops down on to the footwall along any openings, or fractures or cracks which offer a more favourable site for retention of gold. The concentration of gold along the footwall of the vein is further enhanced by the presence of uneven and rough surface along the footwall (Fig 19). This aspect seems to have been known to the earlier British mining engineers and hence while sampling the drives and stopes after each blast, the samplers would also cut 3 inches of the footwall and hangingwall contacts as a part of the reef width and generally if not always the Footwall portion of sample would assay more gold than the hangingwall portion of the lode.

The following is an extract from the 1932 sample record of the Mysore mine which shows the assay values both along the hangingwall and the footwall . It is clear from the Table 10 that there is higher concentration of gold along footwall roughly in 2/3 of the 36 total locations, which shows probably that the gold migrating along the hangingwall contact dropped on to the footwall contact, along with any gold that may be moving through the footwall contact also.

Kirmani et al (1998) have also noted that the footwall has anomalous high gold values in the Au bearing volcanogenic massive Cu, Zn, deposits at Danva in Rajasthan.

The above case studies give a clear idea of the higher gold values along the footwall contact of the Champion lode, which dips at low angle (in the upper levels), may be attributable to earth's gravity.

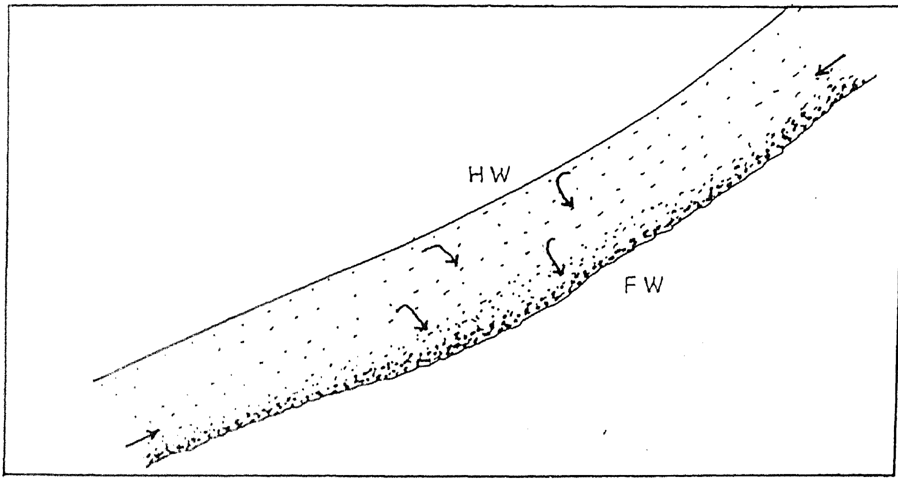


FIG. 19 : MORE GOLD IN FOOTWALL DUE TO GRAVITY

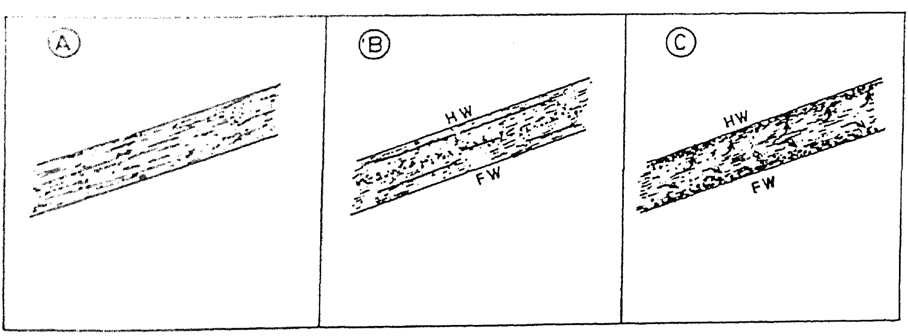


FIG.20: MORE GOLD CONCENTRATION ALONG FOOT WALL AND HANGING WALL CONTACTS WITH COUNTRY ROCK WHICH ACTED AS BARRIERS

Table - 10 Distribution of gold along FW and HW of the champion lode.

Name of the Mine — Mysore Mine
Section — Ribblesdale shaft
Location — Level 46 North

Sample Sl. No.	Date	Width (inches)	Assay values (dwt) (1 dwt - 1.71 gram)
1	22.10.1932	HW 30 FW 30	4 11
2.	3.11.1932	HW 29 FW 29	14 11
3		HW 28 FW 28	9 11
4		HW 28 FW 28	3 2
5	16.12.1932	HW 29 FW 29	11 35
6	10.1.1933	HW 15 FW 15	6 12
7		HW 4 FW 3	3 6
8	22.10.1932	HW 32 FW 32	5 25
9		HW 27 FW 27	21 6
10		HW 37 FW 37	5 86
11	3.11.1932	HW 28 FW 28	7 1
12		HW 27 FW 27	4 316
13	22.11.1932	HW 28 FW 28	7 1
14		HW 31 FW 31	4 3
15		HW 29 FW 29	57 19
16		HW 30 FW 30	50 66
17		HW 26 FW 26	45 281

18		HW 30 FW 30	50 66
19		HW 26 FW 26	45 281
20	5.12.1832	HW 28 FW 28	22 53
21		HW 36 FW 36	102 19
22	5.12.1932	HW 33 FW 33	1099 110
23		HW 30 FW 30	54 152
24	9.12.1932	HW 36 FW 36	5 174
25		HW 37 FW 37	41 39
26		HW 33 FW 33	173 110
27	16.12.1932	HW 26 FW 27	7 230
28		HW 29 FW 29	3 3
29		HW 42 FW 42	44 51
30		HW 30 FW 30	71 158
31		HW 38 FW 38	131 11
32	21.12.1932	HW 17 FW 30	1 93
33		HW 30 FW 30	33 174
34	3.1.1933	HW 22 FW 32	18 161
35		HW 43 FW28	47 136
36		HW34 FW28	75 294

4.3.2 Higher concentration of gold both along the footwall and hanging wall of the lode due to the wall rocks acting as barriers:

It has been observed that at a few places as shown in table 10, the Champion lode shows higher values on the hangingwall or more or less equal concentration of gold both along the footwall and hangingwall contacts (Nos. 4, 14, 18, 25, 28 and 29) than in the middle of the lode. But, this is not a universal phenomenon. There are several exceptions to this possibly because of other factors, which play a role in the enrichment of gold. The higher concentration of gold both along the footwall and hangingwall contacts can be explained by the following possibilities. When the mineralising solutions start ascending, second generations of fractures develop in the quartz vein, possibly by the force exerted by the rising ore bearing solutions and the ore will also get lodged in the newly available spaces.

With continuous pumping of the mineralising solutions, the fractures in the quartz get saturated and when there is no more room for deposition of gold, the solutions move towards the footwall and hamgimgwall contacts of quartz lodes with the host rock. These contacts are physically the planes of weakness between two contrasting litho units. The footwall and hangingwall contacts act as ideal receptacles and also act as barriers to prevent gold migrating in to the country rock. The footwall receives more gold due to the influence of gravity, for the placement of the gold bearing solution. Thus the footwall and hangingwall contacts of the lode with the host rock form ideal places for deposition of metal and act as barriers to prevent the gold from spilling into the host rock. The above process is explained in Fig. 20 and described in the following 3 stages.

1. Formation of fractures in the host rock and filling by quartz material and gold.
2. Formation of second generation of fractures F2
3. Filling up of the F2 fractures in the quartz by gold, mostly along footwall and hangingwall contacts which act as barriers.

In summary, it can be stated that the footwall and hangingwall contacts act as barriers for gold bearing solutions and permit precipitation of gold although with better efficiency along the FW contact due to the influence of gravity. These wall contacts also prevent the gold from spilling into the wall rocks (country rock).

4.3.3 Fractures developed due to the settling of the hanging wall block

In a low angle dipping fracture filled lode as in the case of the Champion lode at shallow depths, the original fractures are first filled by quartz and later by auriferous solutions or emanations giving rise to a typical vein deposit. During the process if the fractures in the hangingwall blocks are not fully filled up and are not fully healed by gauge and other minerals, it is likely that due to gravity the hangingwall block will settle down slowly on the footwall block. As a result new and secondary fractures are developed on the hangingwall block which are generally parallel to the original fracture filled lode. Such fractures, if other factors are conducive, may also get filled up by quartz and later by gold giving rise to a hangingwall lode of limited length and depth (Fig.21).

There is a small parallel lode about 500' to the west to the Champion lode in the Champion mine which is called Mundy's lode. It is not exposed on the surface. The Mundy's lode (Fig. 22) is localised in the Tennant's shaft of the Champion mines, almost at the centre of the mining field. It is more like a blind ore body and has been explored from 200' feet level to 1800' level in the Tennant's shaft in the Champion mine. This lode may have been formed due to the development of a fracture consequent to the settling of the hangingwall of the Champion lode.

Just like the Champion lode the Mundy's lode is also localised within a typical komatiite. A special feature of this lode is that the width of the vein is less

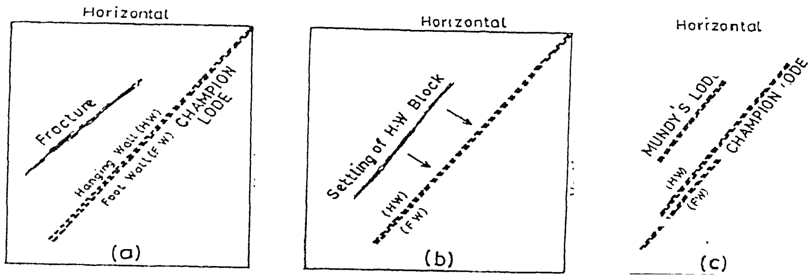


FIG. 21: DEVELOPMENT OF NEW LODE DUE TO SETTLING OF HANGING WALL BLOCK

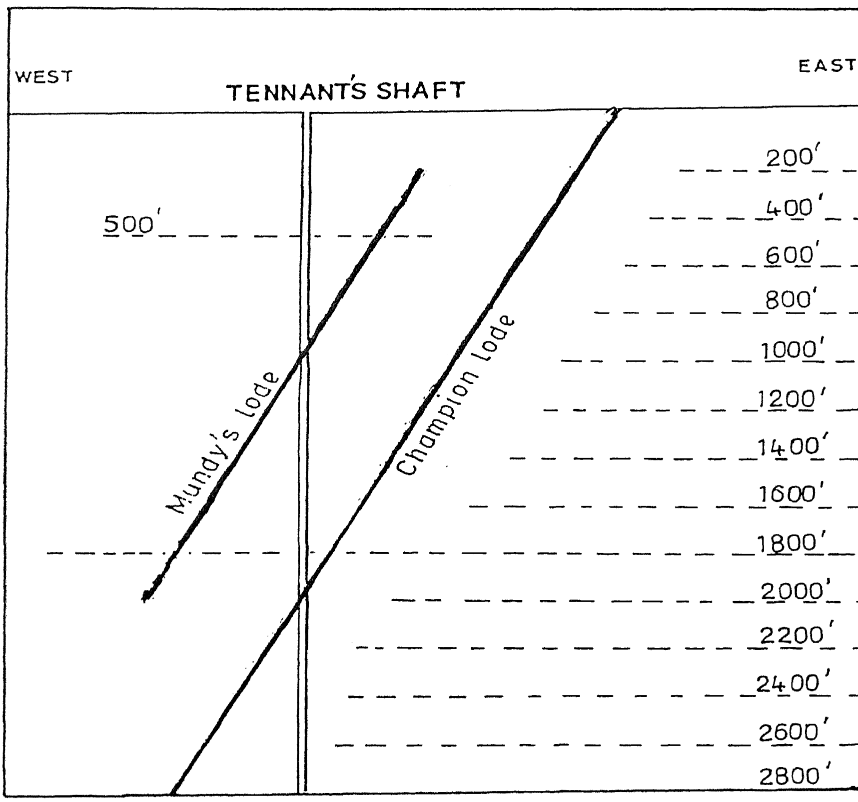


FIG. 22: POSITION OF MUNDY'S LODE WITH REFERENCE TO CHAMPION LODE

than 6" and there is no well developed alteration zone around the Mundy's lode, which possibly show that the Mundy's lode occupies a fracture formed due to the settling of the hangingwall.

The contribution of gold from Mundy's lode with limited development and stoping is not much when compared to the main Champion lode but the Mundy's lode is more of geological interest than of economic interest. Perhaps, because of its proximity to the Champion lode, the earlier British mining engineers started exploring the Mundy's lode also since it did not warrant sinking of new shafts. Attempts made to locate the southern extension of Mundy's lode in the Mysore mine on the basis of geochemical studies and by geometric projections were disappointing.

What ever may be the size, shape and depth persistence and grade of the Mundy's lode, it has made a positive contribution to more gold in the upper levels.

4.3.4Sharp changes along the dip and strike of lode

It is a wellknown fact that the rich ore shoots are associated with the sudden changes in strike and dip of an ore body. The Champion lode in the upper levels dip at 45° to 65° towards west while in the lower levels it becomes steeper to near vertical. In the upper levels better slope is provided for retention of gold in the fractures compared to the steeper portions at lower depths, because of influence of gravity. Occasionally where the lode abruptly changes its course, particularly along the dip, sharp bends in the form of concave loops or kinks will result. These bends make ideal sites for extra deposition and retention of gold. Such examples in the upper part of Champion lode workings are present in all the mines. This aspect can be very well appreciated in the Champion lode along the dip (Fig.23.)

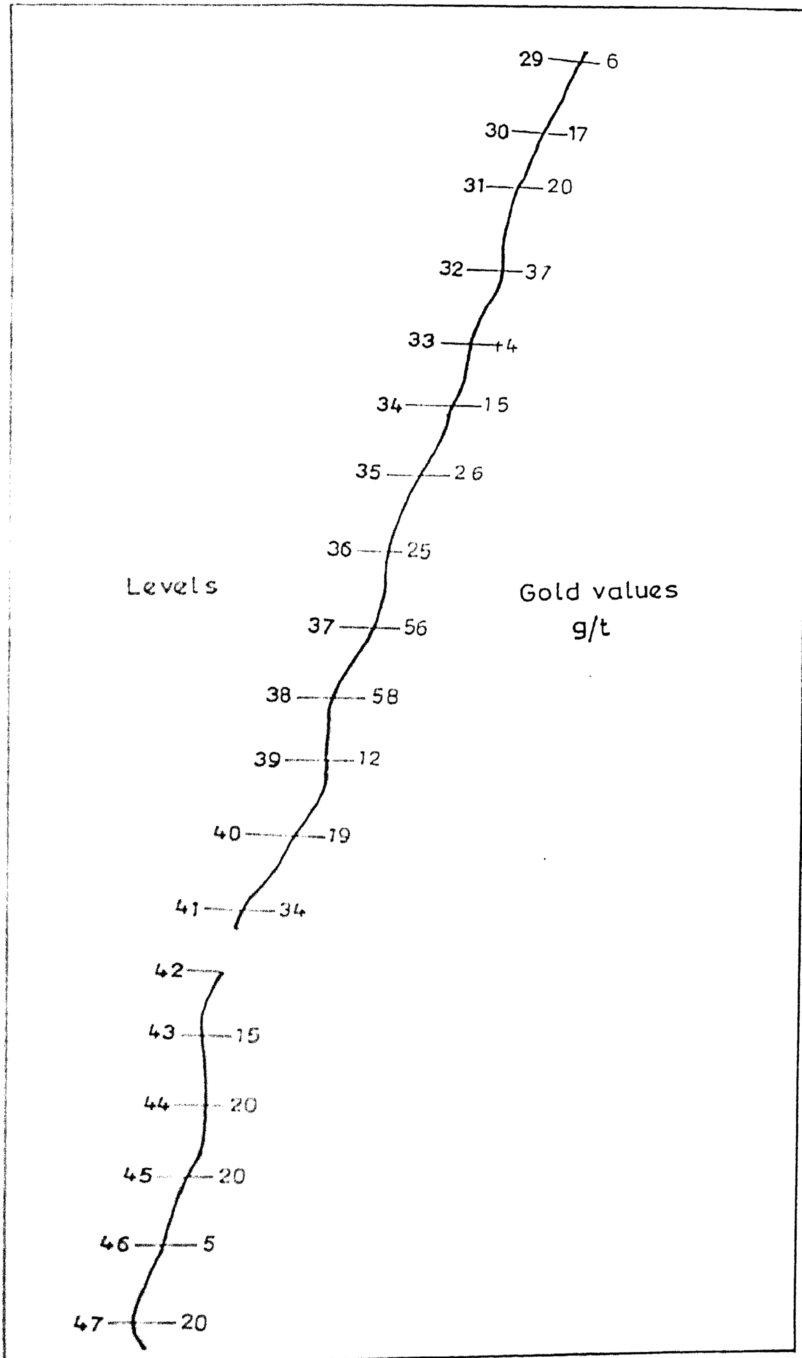


FIG ·23: HIGH GOLD CONTENT ALONG BENDS OF FOOT-WALL LODE BETWEEN 30 AND 47 LEVELS IN WALLROTH'S SHAFT, OORGAUM MINE

The high concentration of gold along bends and curvatures of Champion lode is further confirmed by the inclined winzes sunk from level to level. Normally winzes are sunk on high gold values and are developed vertically to the next lower level. As long as the lode dips at a particular angle, the winze follows the inclination of the ore body. But when the lode makes a sudden change in the dip, then the development of winze is realigned to follow the change of dip of the ore body. The following are some of the examples of inclined winzes developed on high gold values in the Balaghat mine as shown in Fig. 24.

The curvatures and bends along the strike of the Champion lode are less evident because most of these curvatures pass off into minor undulations.

But, whenever there are gentle curves along the strike of the lode, the width of the ore body and the gold value get marginally improved which is not perceptible always. But the very fact that the curvatures definitely have increased the length of the ore body indirectly contributing to more gold. So the sharp bends and kinks in the Champion lode particularly along the dip have made a significant contribution to the enrichment of gold in the upper levels of Kolar Gold Mines. In contrast to this, there are no significant bends in the lower levels because the champion lode dips steeply.

4.3.5 "Horsetail" effect of the fractures giving rise to multiple auriferous veins

The Champion lode is made up of quartz containing impersistent fractures, which were filled later by gold. These fractures are probably formed due to tension, which pull apart the rocks. The fractures are able to keep open for the precipitation of mineralising solutions. With diminishing pressure, the tension fractures as they travel towards the surface becomes weak. According to Nicholas (1986) these may form "Horse- tail" pattern of thin, long impersistent veins. The horsetail pattern may be symmetrical or asymmetrical. In Kolar Gold

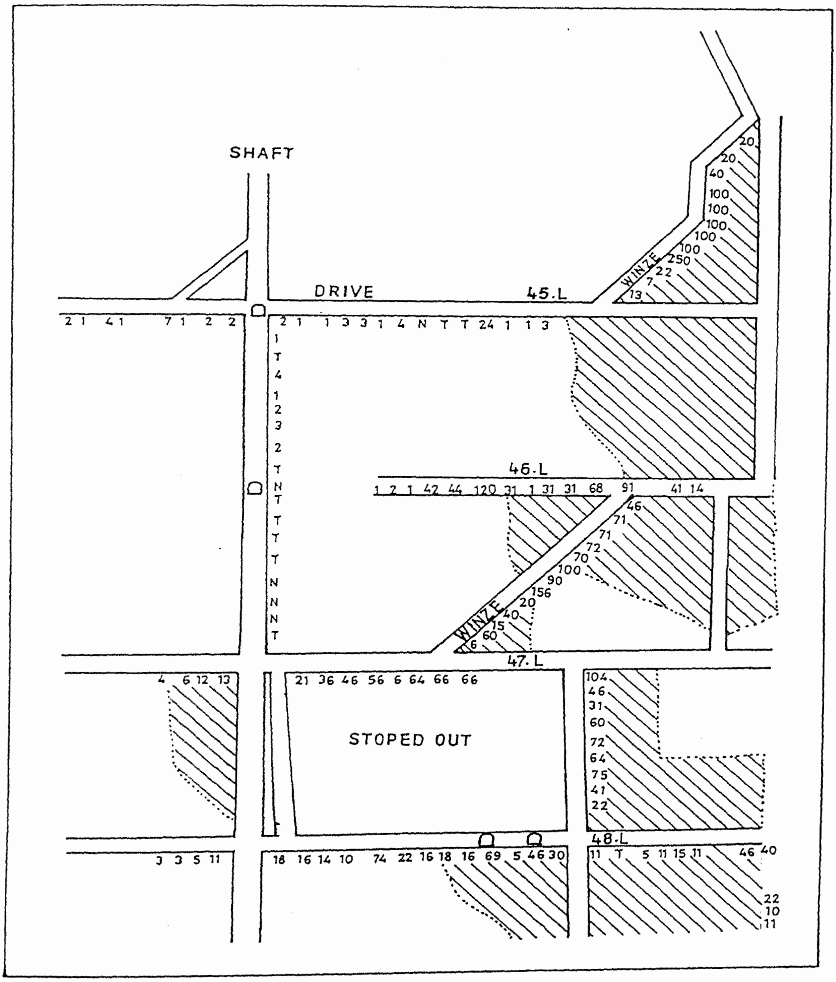


FIG-24: HIGH GOLD VALUES IN THE CURVES OF CHAMPION LODE AS SEEN IN INCLINED WINZES IN BALAGHAT MINE

Mines, there are two areas where the tension fractures terminate with a symmetrical horse tail pattern as they reach the surface (Fig 25). Table 11 shows the details of number of veins developed due to tension giving rise to horse tail effect in Oorgaum and Champion mine.

Table-11. Showing the number of veins of Champion lode formed due to horse tail fracturing in Oorgaum and Champion mines

	Depth (ft.)	No. of veins
Along Oaklay's shaft (Oorgaum mine)		
	Surface - 500'	4
	500' - 1000'	3
	1000' - 2000'	2
	Below 2000'	1
Along Wallroth's shaft (Champion mine)		
	Surface - 1250'	3
	1250' - 2000'	2
	2000' - 2250'	3
	2500' - 3500'	1
	3500' - 4000'	2
	Below 4000'	1
Along Glens shaft (Champion mine)		
	Surface - 500'	5
	500' - 1000'	3
	1000' - 1500'	2
	Below 1500'	1

From the above, it is obvious that due to "horse-tail" effect, the Champion lode has multiplied into several branches thus enhancing the overall linear length of the Champion lode giving rise to multiple auriferous quartz lodes leading to enhancement of gold by 3 to 4 times.

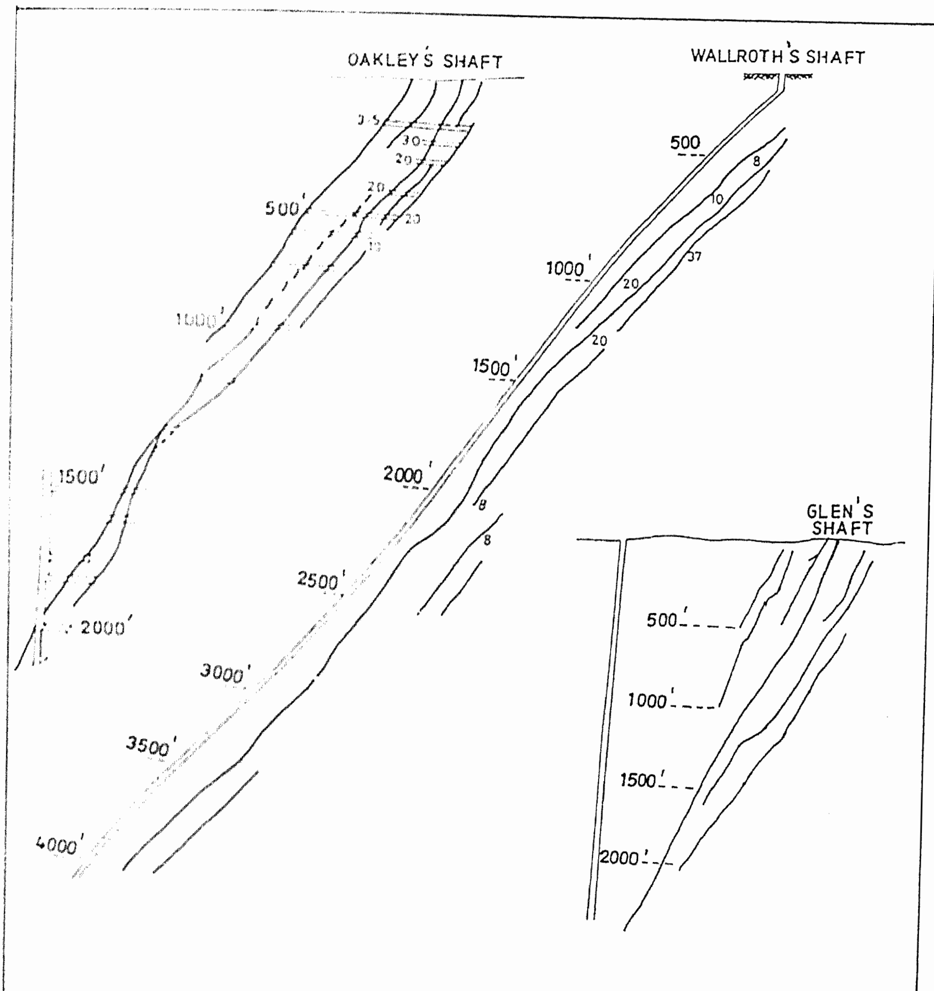


FIG. 25: HORSE TAIL FRACTURING OF THE CHAMPION LODE.

Therefore, the "horse-tail" effect of the Champion lode has made a positive contribution to the high incidence of gold in the upper levels of Kolar Gold Mines.

4.3.6 Convergence or intersections of fractures giving rise to fold effect

The Champion lode is not a single lode but is made up of a series fractures with many breaks and makes. These fractures are of various dimensions and shapes. Some are parallel, some are of en echelon pattern and others are of diagonal type. These diagonal fractures where ever they converge, they give rise to zig-zag type fractures which when get filled up by quartz, and later by gold bearing solutions, assume the shape of a pseudo-fold in the shape of V or N or W or Z (Fig.26). If two diagonal fractures meet, it gives rise to a simple 'V' fold. Wherever two parallel fractures are intersected by a diagonal fracture, it gives rise to a 'N' or 'Z' shaped fold. Occasionally when two parallel fractures are intersected by two diverging or converging fractures, it gives rise to 'W' shaped fold effect. Pryor (1923) who studied the underground geology of Kolar Gold Mines when the mines had reached a depth of 6000 feet also felt that the so called folds are not really folds, but they are only intersection of fractures. This observation was based on the absence of any changes in the foliation dips of the country rock around the quartz filled fractures.

The Champion lode displays "fold-like" habit at a number of places mostly in the upper levels in all the 4 major mines i.e. Nundydroog, Oorgaum, Champion and Mysore mines.

In Nundydroog mine, the fracture intersections in the Richards shaft area is only 150 feet long along the strike but it is 1500 feet long along the pitch and they persist from 1600' level to 2200' level (Fig.11 A).

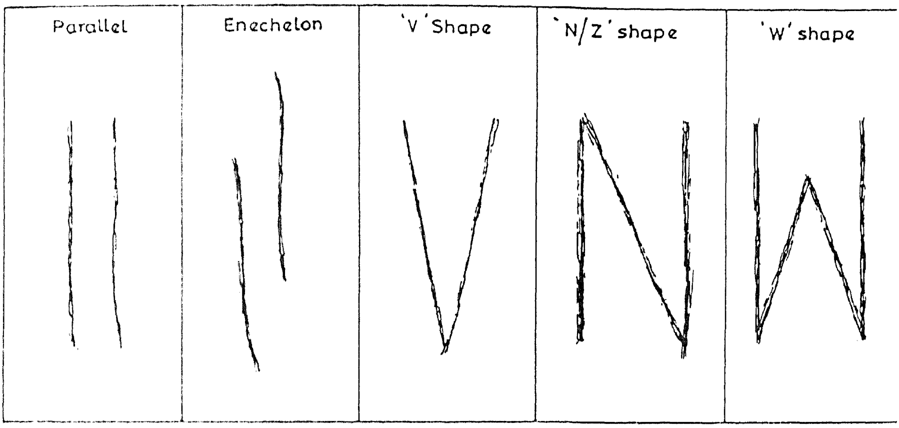


FIG.26 : CONVERGENCE OR INTERSECTION OF FRACTURES GIVEN RISE TO FOLD EFFECT

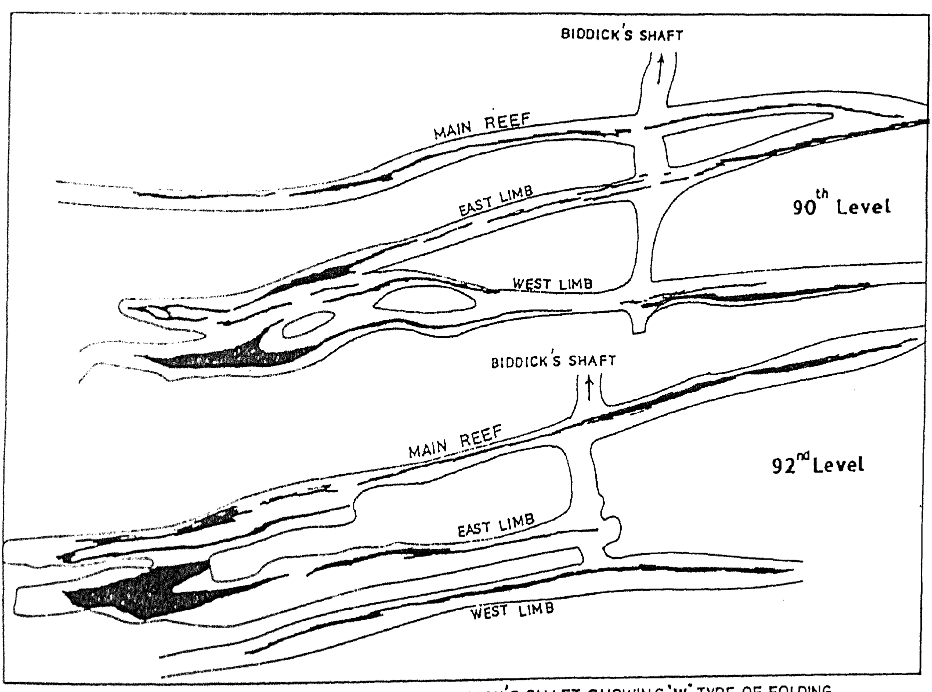


FIG.27: PLAN OF 90 AND 92 LEVELS IN BIDDICK'S SHAFT SHOWING 'W' TYPE OF FOLDING

In the Oorgaum mines, the intersection of fractures in the Bullen's shaft area is 900 feet along the strike and 870 feet along the pitch and they persist along the pitch from 3400' level to 4400' level (Fig.11 B).

In the upper levels of Champion and Mysore mine the fracture intersections are called Champion lode and its eastern branches. These occur as parallel lodes with a dextral shifting in an en echelon pattern and are spread out rather discontinuously along the strike for about 4500' and along the dip it extends to 4000' depth. These eastern branches occur as overlapping branches with occasional convergence giving rise to nose of folds in Glens shaft in Champion mine (Fig.11 C) and in Ribbledale's shaft in Mysore mines (Fig.11 D).

Along the convergent limbs and noses, the width of the lode and the average gold content of the lode gets enhanced, particularly at wall contacts with the lode and at the sites of intersection of two branches. With the result the lode length either doubles or triples at some places enhancing the total linear length of the ore body resulting in gold concentration. Such intersections of fractures have substantially contributed to the high incidence of gold in the upper levels. A " W " type of intersection of fractures is also seen in the lower levels of the Biddick's shaft of Champion mines from 7500' to 9500' depth over a length of about 300 feet only (Fig 27 and Fig 28).

In the southern most part of the Kolar Gold Mines i.e. in the Mysore mine, the eastern branches of the Champion lode occur as overlapping en echelon fracture filled lodes which intersect giving rise to noses and pseudo folds. These folds extend up to 3000 feet depth. These various branches are called Green, Red and Brown lodes in order of importance (Fig 29). These three northerly pitching lodes together may be also considered as horse tail pattern and have contributed to a large extent to high enrichment of gold in upper levels of Kolar Gold Mines. These lodes were so rich that the Mysore mine was able to survive on its own till 1992 after having worked for more than 110 years. This is largely due to

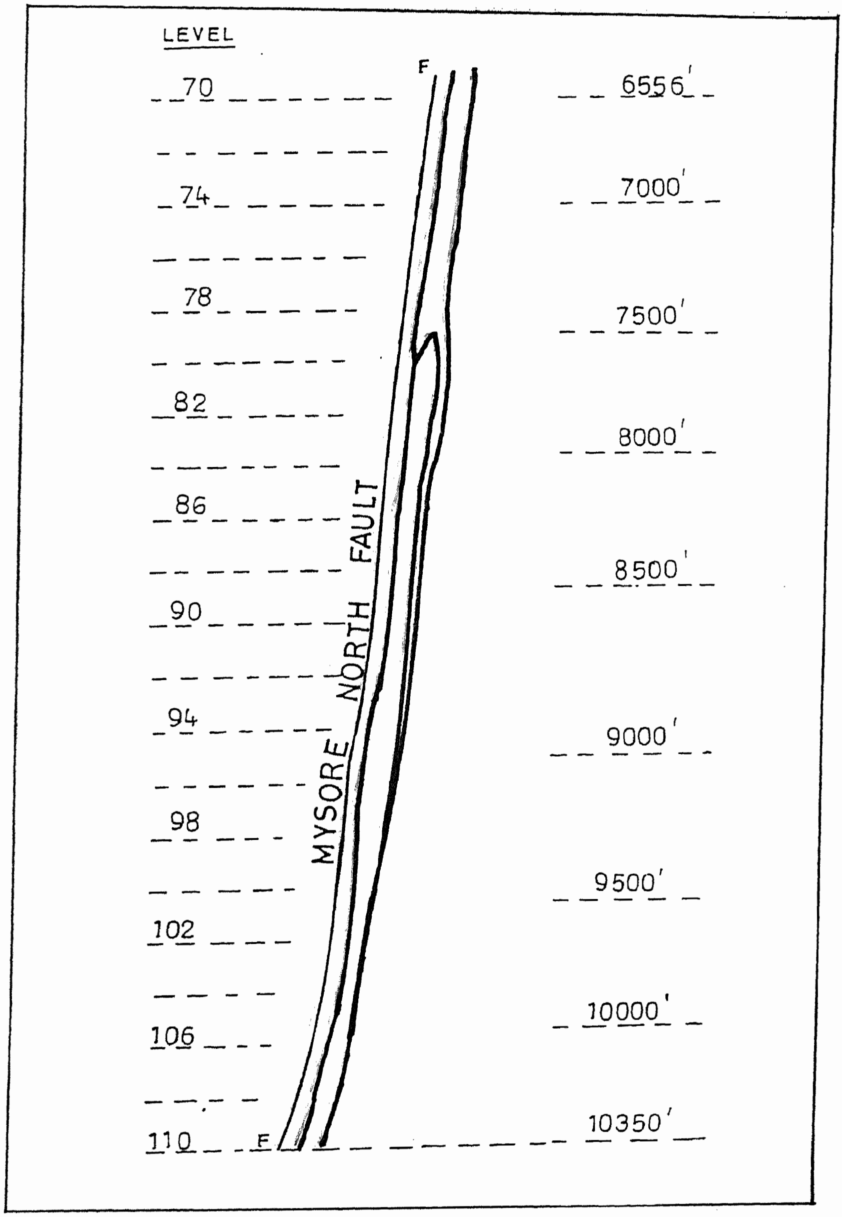
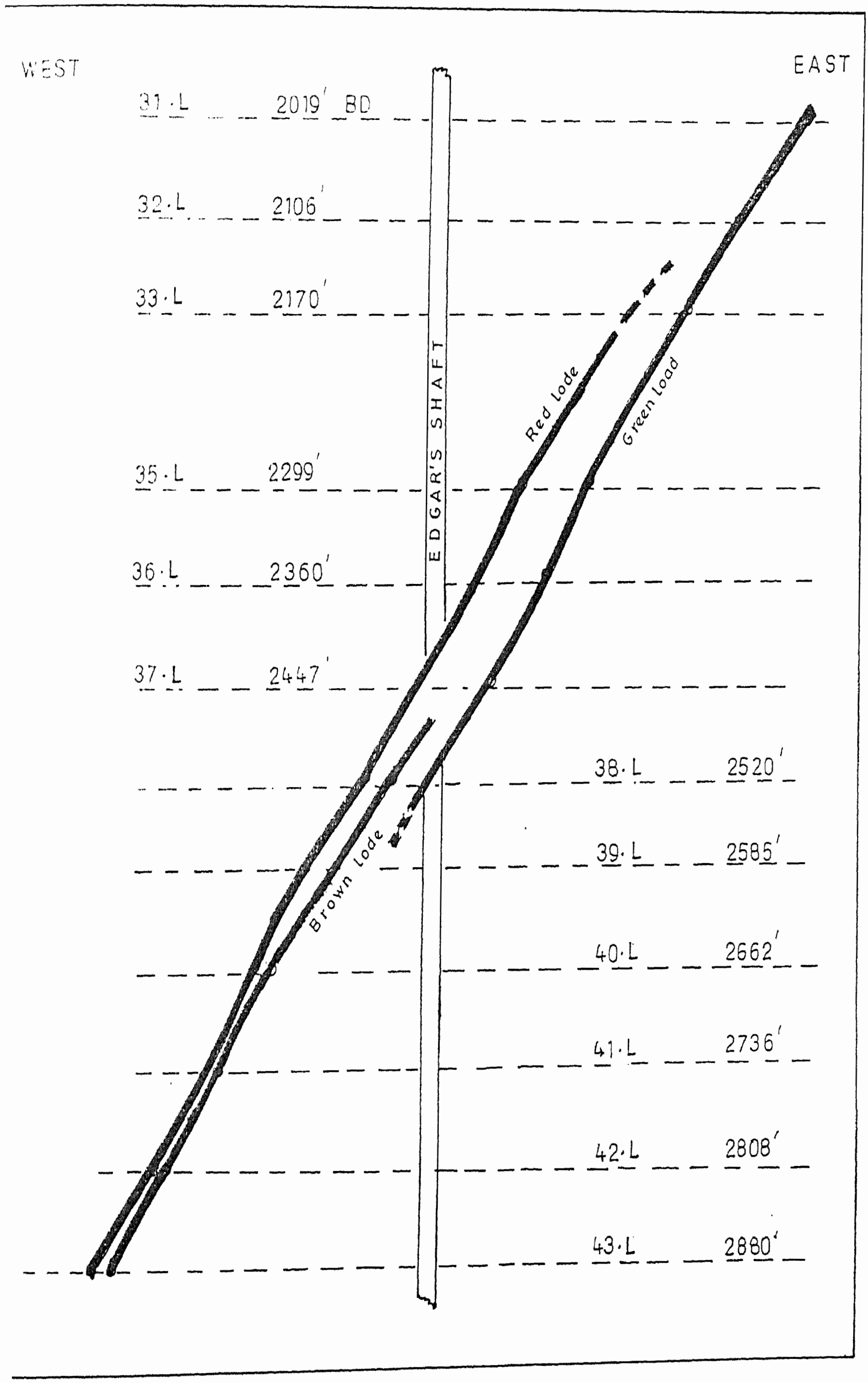


FIG-28: SECTION OF BIDDICK'S SHAFT (CHAMPION MINE) SHOWING 'W' TYPE OF TIGHT FOLDING



FIG·29: CHAMPION LODE IN MYSORE MINE (ACROSS EDGAR'S SHAFT) DISPLAYING 'HORSE TAIL' FRACTURES IN VERTICAL SECTION

converging fracture filled branches of the champion lode. Thus the convergence and intersection of fractures is another major geological factor for high concentration of gold in the Champion lode both in the upper and lower parts of the Kolar Gold Mines.

4.3.7 Low angle dip of the ore body

The Champion lode is a fissure filled ore body made up of several ore shoots of different dimensions (Fig.10). The Champion lode although dips towards west, the amount of dip varies at different depths and it is shown below.

Table 12. Dip of the Champion Lode at different levels in the 3 mines

Mine	Top levels (surface - 3500' depth)	Middle levels (3500 - 7000' depth)	Bottom levels (7000 – 10500' depth)
Mysore	35 - 46°	50 - 68°	80 - 85°
Champion	42 - 61°	69 - 74°	80 - 86°
Nundydroog	35 - 60°	68 - 74°	80 - 85°

For purpose of this study, we can assume that the dip in the upper levels (surface to 5000' depth) varies from 35° - 60° towards west. These low angle dips of fractures provide a better receptacle along footwall for the gold mineralisation as already mentioned in section 3.4. This is further facilitated if the footwall is serrated and jogged by rough edges etc.

The following is an extract from the observations made by Boyle (1979) on the grade of the ore bodies, which dip at less than 45 (Fig.30 and Table 13).

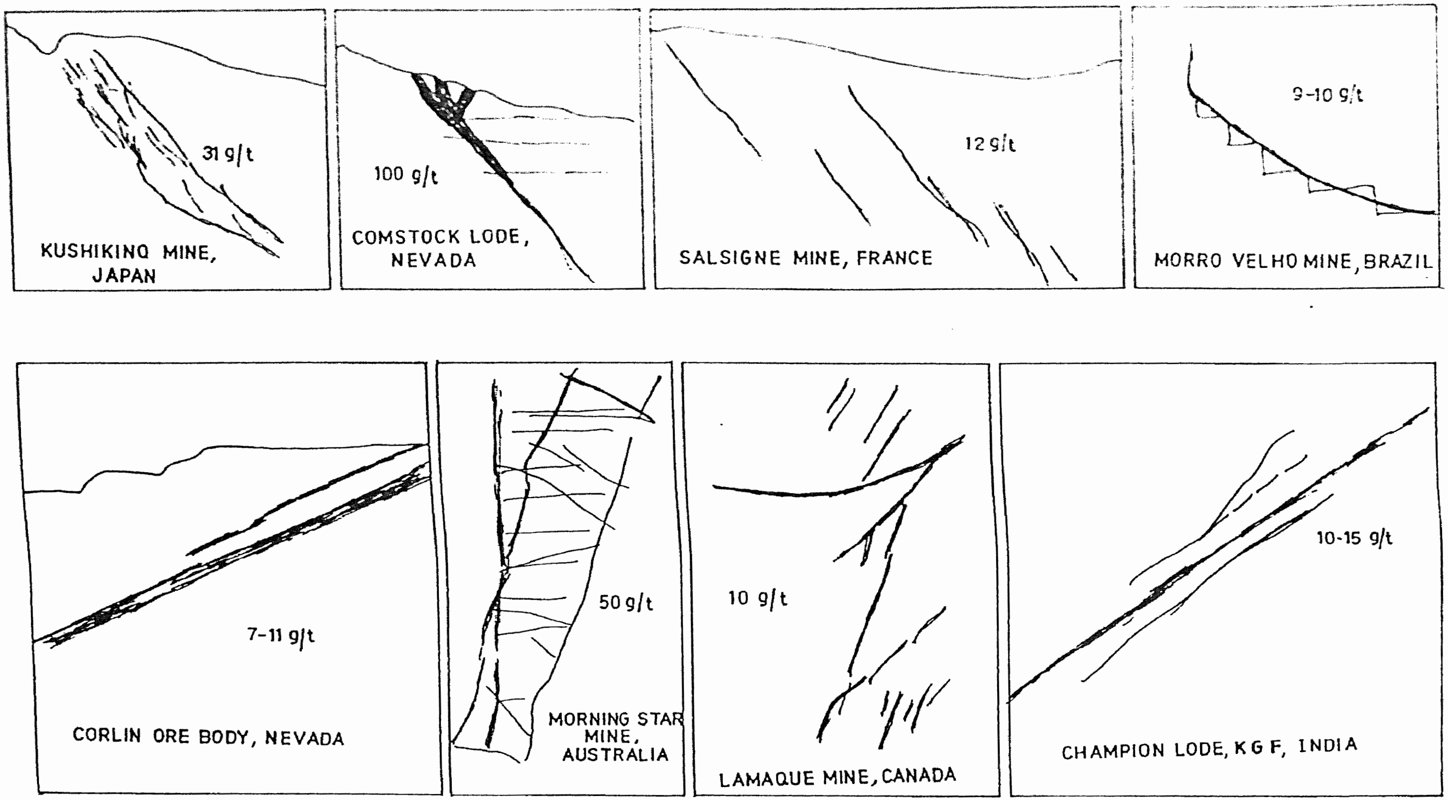


FIG.30: HIGH GOLD VALUES IN LOW DIPPING ORE BODIES

Table – 13 Grade of the ore bodies which dip at less than 45°
(Modified after Boyle-1979)

Name of mine	Dip of Orebody	Grade (g/t)	Reference pages of Boyle's Book
KUSHIKNO MINE (JAPAN)	40° E	31.00	269
MOHAWK-JUMBO LODE (NEVADA)	40° E	100.00	271-273
COMB STOCK LODE NEVADA	45° E	150.00 (UPTO 1000' DEPTH)	274
CAMLAREN MINING CANADA	45° W	21.00	282
SALSIGNE GOLD MINING, FRANCE	40-50° E	18.00	286
LAMAQUE MINE, QUBEC	40-50° S	10.00	299
MORNING MINE, VICTORIA, AUSTRALIA	30-40° S	100-300	300
MORRO VELHO MINES, BRAZIL	40° E	12.0	305
CARLIN OREBODY, NEVADA	30°	6-10	309
TARKWA GOLD FIELD (GHANA)	25° W	30	326
CHAMPION LODE, INDIA	35-60° W	above 10	Subbaraman (Kolar mine data)

From the above details we can conclude that the low angle dip of the fractures is an important geological factor, which favour high concentration of gold. However, in Champion lode the low angle dips are restricted to 3500' depth and hence the role of low angle dip is significant in the concentration of gold (more than 10-15 g/t) in the upper levels only.

Bichan (1947) who examined the Mysore mine underground workings said that "in flat dipping section of the quartz veins, there has been a concentration of gold towards the footwall. 68% of the cases studied followed this rule and the degree of concentration was 77%. It seems that there has been a degree of gravity concentration".

4.4 Host rock and source rock

The Precambrian rocks of the Kolar Gold Field are of volcanic origin and are generally referred to as belonging to a greenstone belt or as auriferous schist belt of eastern Karnataka (Radhakrishna and Vaidyanathan, 1997).

According to Emiliani 1997) the greenstone belts include the oldest rock section of the earth. They were formed at low temperatures (300-400°C) at moderate pressures (1.5 to 15 KB = 5 to 50 Km of depth). A typical greenstone belt consists from bottom (a) to top (c) of the following sequence.

(c) Graded volcanic clastic sediments (mainly greywacks)	10%
(b) Felsic volcanics (andesites and rhyolites)	25%
(a) Ultramafic to mafic volcanics (komatiite to basalt)	65%

In India and Western Australia the greenstone belts are believed to have a thickness ranging from 180 to 30 Kms.

To understand the geological significance of the gaps in the stoping operations, in the Kolar Gold Mines, Subbaraman (1980) undertook a detailed underground mapping of southern parts of Mysore mines on the Champion lode, from surface to 4000 feet depth and established Komatiite as the host rock for the Champion lode Fig 13). This is further confirmed by the mapping (Peshwa, 1997) of the underground levels of Glen's shaft of Champion mines (Fig 31 and Table 14) and Hancock's shaft of Mysore mines (Fig 13). Subbaraman (1980) concluded that the komatiite occurs as detached lenses or boudins formed due to folding and other structural deformations (Fig 13).

Table 14- Gold values in komatiites in the cross cuts of 340 ft level of Glen's Shaft, Champion mine

Name of Cross cut	gold in g/t	length of cross cut (ft)	Remarks
1	3.5(20) on North wall 1.2(20) on South wall	60	E. of shaft
2	12.8(2) on North wall 2.2(2) on South wall	20	W.of shaft

Note: Figures in the brackets indicates the no. of samples

Based on the underground geological mapping, (Fig.13) the gaps in the stoping were attributed by Subbaraman to the absence of komatiite between the boudins. This is in confirmity with the idea of Pryor (1923), who examined the underground geology of Kolar Gold Mines and made the following observation, which is significant. " One type of amphibolite found in the underground workings deserves special mention. The amphibole in it is in little radiating or fan shaped or tufted aggregates as patches of chlorite and talcose matter, this type of amphibolite is almost invariably present on one or other walls of the lode and it forms a casing to the lode".

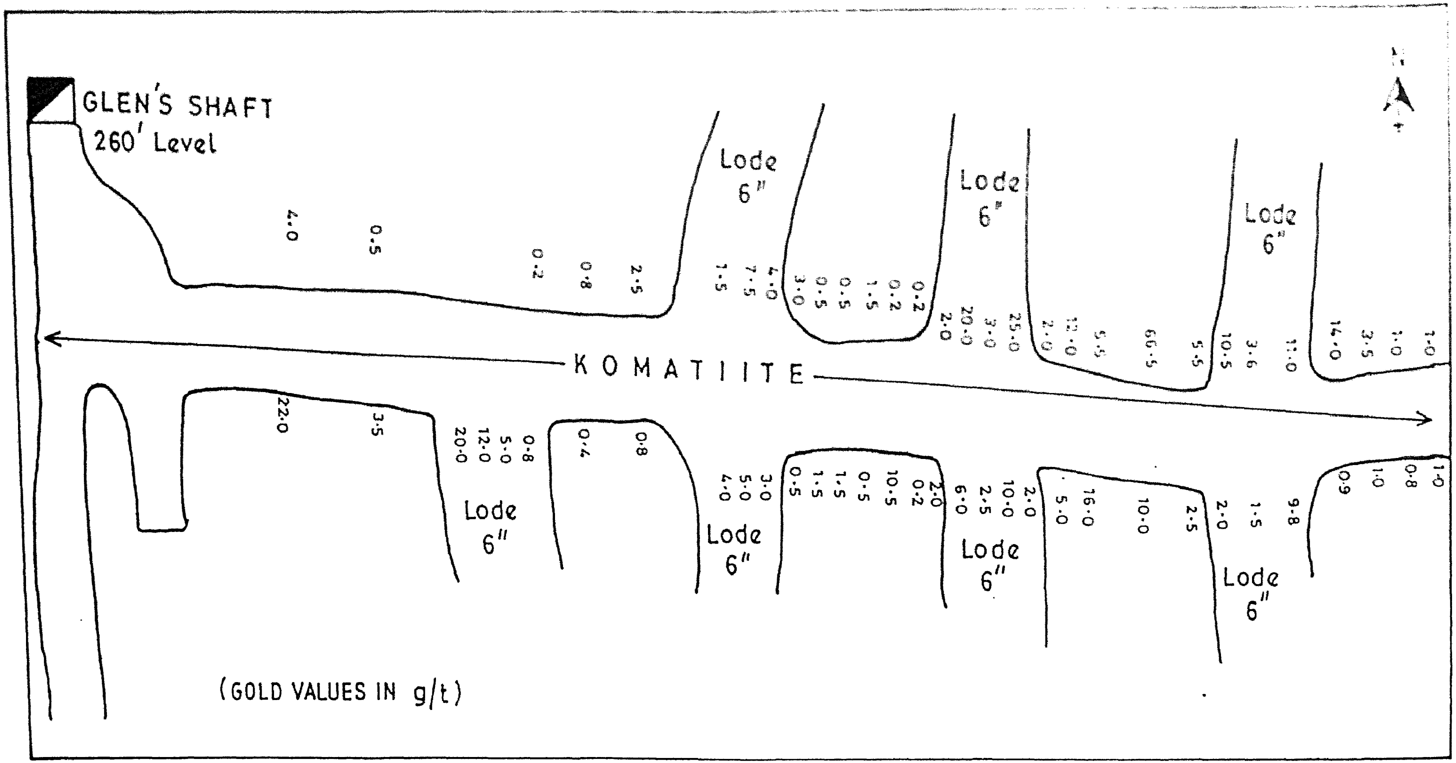


FIG.31: GOLD VALUES IN KOMATIITE IN 260 LEVEL OF GLEN'S SHAFT, CHAMPION MINE

Similarly Bichan (1947) observed "a common variety of hornblende schist encountered near the Champion lode is tufted amphibolite in which hornblende occurs as radiating aggregates. This may be taken as an indication of recrystallisation under the influence of considerable pressure".

The tufted amphibolite which is a high magnesium basalt (now called Komatiite) exhibits spinifex texture. According to VilJoen and VilJoen (1979a) the komatiites represent the most spectacular examples of quench olivine texture found in the ultramafic lavas of Archaean terrane where the texture consists of abundant skeletal olivine blades is known as spinifex. According to Nesbit (1979) the word spinifex is derived from a type of grass wildly grown in Western Australia. Komatiite has been reported from the Kolar Gold Field by several workers, notably by Dutta et al (1969), Viswanath (1974, 1979), Ananth Iyer et al (1979) and Rajamani et al (1981, 1985). But the relationship of these rocks to gold mineralisation has not been demonstrated. Atabek 'yants (1984) carried out major, minor and trace element analysis of the Kolar Gold Field rocks and concluded that the auriferous lodes of Kolar Gold Field are epigenitic and hydrothermal in origin but he could not link the gold to the Komatiite. However, Divakara Rao et al (1976) who studied the subsurface hornblende rocks from the Nundydroog mines on the Champion lode reported that the Kolar amphibolites are similar to the tholeiitic basalts in Al_2o_3, Tio_2, CaO and Na_2o, where as Fe_2o_3, Mgo are less and K_2O and Fe_2o_3 are more in the later. This suggests that the overall composition of Kolar amphibolites is similar to continental tholeiites.

Subramanyam et al (1991) carried out a detailed study of the geochemistry of the auriferous lodes and host rocks of Kolar Gold Mines and reported that the Champion lode is confined to the komatiitic basalt. "The komatiitic basalt shows spinifex texture and is made up of either tufts of amphibolite or curvilinear and linear bundles of amphibolite and appears to be almost monomineralic in the hand specimen. The tufted nature is not universal, massive variety is also seen. Under the microscope the rock is characterised by a preponderance of rod like amphibole

(actinolite) with subordinate interstitial plagioclase and accessory hornblende, chlorite, pargasite and quartz". On the basis of the above, and also on the observations made in the mine workings, it is confirmed that the komatiite is the host rock for the Champion lode in the upper levels.

Subramanyam et al (1991) have pointed out that for any genetic model for gold mineralisation, we have to take into consideration the following three factors:

(1) The primary source of gold
(2) The mechanism of mode of transport of gold and associated elements.
(3) The factors causing localisation of gold in structurally favourable host rock.

The present research work is an attempt to answer the third factor mentioned above. Many recent workers Subramanyam et al (1991), Balakrishna et al (1988), Rajamani et al (1985), Viljoen et al (1970), Pyke et al (1975, 1980) hold the view that the source rock for gold and associated elements in the Champion lode is mainly the enclosing volcanic sequence of rocks. This is largely based on the fact that the basic and ultra basic (Komatiite) rock sequence which makes up the bulk of the host rocks for the gold deposits spread in the greenstone belts all over the world have a high background value of gold in contrast to the less basic or acidic rocks.

The Table-15 adopted from Subramanyam gives the background gold values in the different rock types all over the world. In this table the data on the host rock (komatiite) of the Champion lode and Mundy's lodes of Kolar Gold Mines is also included.

The Table-15 highlights that the Komatiites and other greenstone rocks are significant host rocks for the gold in the gold fields in W. Australia, S. Africa,

Canada, India etc. But there are gold deposits of economic significance in other rocks in the other parts of the world. The mode with which the gold was liberated from these rocks and its remobilisation into the quartz is a vast field of speculation.

However the views of Boyle (1979), are interesting from geological angle. He advocates a metamorphic secretion theory for epigenetic gold mineralisation and visualises the development of strong shears in the greenstone belts during the waning phases of orogeny with concomitant intrusion of granitic bodies. Due to pressure gradient created, the shears literally sucked Co2, H2O, S and other elements from the country rock for thousands of feet around and channelised them towards the surface resulting in high concentration of elements in the shear zone. As a result the chemical equilibrium was disturbed resulting in chloritisation, carbonatisation and pyritisation of the country rock. This leads to liberation of silica, potash, calcite, iron etc in addition to gold, silver and other metallic elements, which then migrate into the secondary dilatants and get precipitated resulting in gold deposits. Boyle who visited the Kolar Gold Mines in February 1985 as a UNDP expert echoed his earlier opinion that the source of gold may have been the extensively sheared schistose belt of volcanics. Viljoen et al (1969) advocates the leaching of gold from the komatiites during carbonatisation. Subramanyam et al (1991) while accepting the komatiites as the possible source for the gold in the Champion lode advocates the views of Emmons (1933) that the intrusive granite played an important role in the formation of gold bearing shear zones. It is possible that the komatiite is also the source rock for the gold in the Champion lode of the Kolar Gold Mines.

Table –15 : Average Gold Contents of Ultrabasic- Basic rock types

Rock type	Au(ppb) Range (No. of Samples)	Arthimetic mean	Remarks
1. South African Greenstone belt	0.1-372(98)	10.8	Saager et al
2. European Ultramafic complexes	0.1-25 (56)	2.0	1982
3. Fe Chemical Sediments, S. Africa	0.46-6667(32)	129.9	Anhaeusser et al 1975
	a) Algoma type	172.6	
	b) Supra type	21.3	
4. Komatiite and related rocks from Barberton area, S. Africa	1.0-1.5(16)	---	Anhaeussar et al 1975
		---	
	5 – 20		Viljeon 1969
5. Interflow sedimentary material from Komatiite sequence, Kambalda, Western Australia	0.2- 1809	142.6	Bavinton and Keays 1978
6. Ultrabasic rocks, dunite, peridotite, pyroxenite, kimberlite, anorthesite Etc.,	0.2- 780 (1185)	11.4	Boyle 1979
7. Basic rocks			
Intrusives- gabbro, norite, diabase	0.3-680(1493)	23	
Extrusives- andesite basalt	0.1-230(1752)	17.4	Boyle 1979
8. Komatiite of Kolar Gold Mines, Karnataka, India			
a) Associated with Champion lode	0.2-66 ppm(92)	0.5 ppm	Subbaraman
b) Associated with Mundy's lode	1.0-97 ppm(853)	1.0 ppm	1999

Note: The Gold values for Kolar Gold Mines are given in ppm

From the point of host rock as a factor for gold enrichment in the upper levels, Subbaraman, (1980) noted komatiite up to about 4000' depth in the Mysore mine. However, below this level up to 5000' depth there appears to be a change in the texture of the host rock from fibrous to schistose or massive nature. Anantha Iyer (1970) who made a study of the geochemistry of the rocks of Kolar Gold Mines area mentions that the fibrous amphibolite is a medium to coarse-grained rock composed chiefly of actinolite, almost free from feldspar. This particular rock type is generally found in the vicinity of the Champion lode. The study of massive amphibolite, granular amphibolite and fissile amphibolite reveal that they are well foliated. This assemblage corresponds to the amphibolite facies of metamorphism. Imperceptible gradational variations from granular to schistose and from schistose to fibrous varieties are observed in the field. From Fig.3 it is quite clear that the ore shoot formation is quite large and rich up to 5000' depth and below 5000' depth the ore shoots becomes significantly smaller and also poorer in grade except in the vent.

Under these circumstances we can assume that the komatiite which is the host rock for the Champion lode in the upper levels (up to 5000' depth) of Kolar Gold Mines must be one of the major factors for high incidence of gold. Subramanyam et al (1991) reports that in the lower levels the tufted amphibolite loses its textural character while retaining its mineralogical characters of typical komatiite. Although there are no definite evidences to prove that komatiite in Kolar Gold Mines is the source rock for gold, the fact that this rock which occurs on either side of the Champion lode in Glen's shaft (Champion mine) and in Hancock's shaft (Mysore mine) - has assayed 2 - 3 g/t for considerable distances away from the lode [(Peshwa (1997) Fig 31]. This is a positive evidence to show that most possibly komatiite by itself (without quartz veins) is auriferous. This type of evidence is also available in the Champion mine from Mundy's lode, which is perhaps a branch of the Champion lode (Exploration Department Note II, 1984). Similarly the fact that most of the major gold mines in the world are

located in the greenstone belt (Fig.1) lends credibility to this view that komatiite could be a source rock for gold for the Champion lode also. (Mine data in Champion mine survey office, KGF).

Subramanyam et al (1991) who examined polished section of the komatiite metabasalt reported occasional presence of minute gold (< 10 μ) at places devoid of any accompanying quartz. They have also recorded up to 100 ppb gold in some of the komatiite rock occurring to the south of Mysore mine. Anantha Iyer et al (1967, 1976) have opined that gold, silica and associated elements were derived from the enclosing mafic rocks. Viswanatha (1974) hinted genetic relation between the gold quartz lodes to the komatiitic metabasalt. Balakrishna et al (1988), Rajamani et al (1985), VilJoen et al (1970), Pyke et al (1975, 1980) also hold the view that the source of gold could be the associated ultramafic rock (komatiite).

These encouraging observations and findings call for a fresh study of the two komatiite rock formations found along the eastern and western parts of Kolar Schist Belt. The eastern Komatiite hosts the Champion and Mundy's lodes for about 25000 ft long (from Balaghat mine in the north and to Mysore mine in the south). Further south this Komatiite continues for another 10,000ft long with impersistant thin quarts veins of low gold values (0.5 – 2g/t). However no special study has been made to evaluate the auriferous nature of the rock itself. Similarly the western komatiite band (about 8000ft west of the Champion lode and close to the western banded iron formation) also deserve restudy. This formation hosts the New quartz lode F which has been tested by pits and winzes. In one of the winzes opened during 1972-75 the komatiite with thin quartz stringers assayed very high anomalous silver values of more than 200g/t over a length of over 500ft and to a depth of 100ft. It also assayed low gold values. This western komatiite which is nearly 20,000ft long and 400ft wide also deserve to be restudied for its auriferous and argentiferous contents.

This study should be taken preferably by the Geological Survey of India as a special project. Besides its economic aspects this study is likely to have great implications of world wide interest about komatiite being a source for precious metals.

4.5 Caught up ore shoots

According to Narayanaswamy et al (1960) the following three main systems of faults have affected the rocks as well as the enclosing lodes in the Kolar Gold Mines area.

(1) NNW - SSE to NW - SE trending faults

(2) NNE - SSW to NE - SW trending faults

(3) East - West to ENE - WSW trending faults

Of the above three systems of faults, NNW - SSE trending fault system is the most important from the point of view of economic geology and mining. The important faults in this system are the Balaghat North Fault Mysore North Fault) and Gifford's fault (Fig.5). The Champion lode, which is 8 km long, is bounded by Balaghat north fault on the north and by Gifford fault in the south. The Mysore North Fault cuts through the Champion lode in the Champion and Mysore mines diagonally. This fault dips at 70° - 80° towards WSW and its effect on the local geology is seen by the offsetting of the rocks and the lode over 400 - 500 feet along the Mysore North Fault and nearly 7000 feet along the Balaghat North Fault.

All the faults in the Kolar Gold Field are post mineralisation and hence they do not carry any gold mineralisation in their fault zones except rarely. The effect of these faults on the enclosing rocks and gold bearing quartz is clear from the mine plans and sections in respect of Mysore North Fault which cuts across diagonally into the most productive portions of Champion and Mysore mines (Fig.10).

The concept of barrenness of gold in the fault zone was understood by Pryor (1922) who examined the underground geology of Mysore mine and reported that no gold was found in the Mysore North Fault zone in Mysore mines.

On surface, the Mysore North Fault has cut through the Champion lode diagonally and has displaced the lode by 100 - 200 ft. horizontally along E-W (Fig.5). In the vertical section (Fig. 10) the Champion lode has been displaced along N - S with a shift of about 400' from surface to 5000' depth. From 5000'-7000' depth the displacement narrows down to 200 feet. Below 7000' depth the displacement is about 500 feet. The widening of this displacement can be attributable to the deflection in the dip of Mysore North Fault from 45° NW to near vertical. Subbaraman (1980) while mapping the underground geology in the Mysore mine from 290' to 4200' levels has observed the termination of the stoping operations at the contact of the fault and resumption of stoping after crossing the fault and picking up the lode in several levels. (Fig. 13).

However, during the course of the present study, it is observed that within the Mysore North Fault zone there are two small but important ore shoots in the upper part of Mysore mine i.e. above the 3000' level (Fig 10). The presence of these two ore shoots in Mysore North Fault zone is unique in nature as it does not conform to the accepted geological principle of the area i.e. absence of gold in the fault zones. This can be best attributable to the effect of shearing of the Champion lode by the fault. In this process, two chunks of Champion lode were perhaps torn from the main ore-body and were dragged and lodged in the fault zone. These ore shoots can be called as "fault-drag shoots". The upper ore shoot is located between 800'- 1000' depth and the lower one is located between 2200' - 3000' depth both within the Mysore mine limits.

Although these ore shoots have been mined out, their geological uniqueness was not realised by the mining engineers during the course of routine mining operations.

The upper fault drag shoot, which was present between 800 - 1000' depth, was roughly of 60 m long, 60 m deep and 1 m wide. This ore shoot might have yielded about 97200 tonne of ore at a grade of about 15g/t yielding 1458 kg of gold. This must have been exploited as a part of normal mining operations with out noticing its peculiar geological placement.

The lower ore shoot, which was present between 2200'- 3000' depth is called the "43 ore shoot" because it was first discovered in the 43rd level. Although this ore shoot was present from 33rd to 43rd levels along the pitch, its existence was not noticed until the mining operations reached the 43rd level. This was because of the belief that no ore exists in the fault zone. According to Srinivas (1980) "the discovery of this ore shoot in 1945 in the Mysore mine at the proximity of Mysore North Fault is a note worthy example of gold enrichment in faults zones. This discovery increased the life of the Mysore mine by 25 years".

Infact, this finding was a major single source of gold production in the Mysore mine at that time. According to Lavi (1980) "the ore reserves of the Mysore mine at the end of 1944 stood at 5,18,000 tonnes at an average grade of 11.9 g/t. The management was toying with the idea of abandoning the mining operation by initiating the extraction of shaft pillars. So the discovery of "43 ore shoot" in 1945 at the 43rd level kept the Mysore mines going for more than 20 years. The net gold yield due to this was 5329 kgs. by crushing 1,58,530 tonnes of ore at a grade of 33.61 g/t. The stoping operations of this ore shoot presented many problems. The area was getting subjected to many rock bursts involving life and property as the ore shoot was heavily stressed owing to its disposition. This shoot was so rich that its ore was used as a 'sweetner' (grade booster) in times of need".

Lavi's description of the 43 ore shoot area as heavily stressed and subjected to many rock-bursts very clearly explains the highly fractured nature of rock of the 43 ore shoot which was situated in the middle of the Mysore North Fault zone

Hence the presence of these two ore shoots well within the Mysore North Fault zone in the Mysore mine has been one of the major geological factors, which has contributed to the enrichment of gold in the upper levels of the Kolar Gold Mines. This type of ore is a rare geological occurrence in a fault zone especially when the faults are post mineralisation in age. These two fault-drag ore shoots together have contributed about 6.85 tonnes of gold. Bateman (1948) mentions about a fault drag ore in Butte, Montona, U.S.A. having been mined in a post mineral fault in which a large amount of drag ore was incorporated in it. Drag ore is generally fragmentary and often finely comminuted and incorporated in the gouge In the Kolar Gold Mines the "43 ore shoot" in the Mysore mine fits aptly to the description of Bateman. Therefore, **"it is necessary to examine in detail all the post mineralisation faults for any possible presence of any drag ore shoots".**

4.6 Micro fracturing and nugget formation

In the published literature on gold nuggets, there are several references for the origin and occurrence of nuggets in the placer deposits. A good review has been made by Boyle (1979). The gold in the placers is of secondary origin after having been released from the primary source such as auriferous quartz lode or some other auriferous rock. Starting from primitive man up to 18th century the quest for gold by man centered along the streams and rivers, which drained the auriferous tracks. It is well known that gold being very heavy is carried down by the streams by gravity, rather slowly compared to other minerals. The tendency for gold to accumulate along the bends and kinks along the streams will give rise

to what are known as "paystreaks". The primitive men who lived along the riverbanks by rearing animals and engaged in cultivation did not know the value of gold. These men collected small gold nuggets from the streambeds more as objects of curiosity than for its nobility. History is packed with examples of adventurous men crossing the seas in quest of gold all over the world. Many of the so-called gold rushes referred to in history (Chapter 1 for details) are related to the placer gold mining. Some of the gold nuggets that were found in these deposits have weighed several kilograms. Even today the placer gold deposits continue to attract prospectors although on a small scale.

However there appears to be no published data on the nuggets related to primary auriferous quartz lodes.

According to Callender (1990) it is not easy to define a nugget. One dictionary states that a "nugget" is a "lump of gold" and suggests that the word may have been originated from Swedish word "Nug" meaning lump or block. In Australia lumps of gold weighing up to 200 pounds have been found and the California gold rush was based on the searches for nuggets. The gold information centre at Madison Square, New York defines a "gold nugget" as a water worn mass of placer gold (a form of natural gold) washed from the rocks that contained it and deposited in river beds usually ranging in weight from approximately 30 grams to 50 kilograms. The heaviest nugget ever recorded named "The welcome stranger was found in Australia in 1869 and weighed 90.9 kilograms.

The Champion lode of Kolar Gold Mines has been worked from 1880 to 1992 and has been systematically exploited by developing the mines, level after level, up to a depth of 10,598 feet. The levels are connected at regular intervals by winzes and rises. The quartz lode has been sampled after every blast of 2-3 feet progress. The total extent of mine development is about 640 kms length. As a result, a vast volume of sample data has been collected and compiled by the respective survey departments of the five gold mines namely Balaghat,

Nundydroog, Oorgaum, Champion and Mysore mines. During the course of the present study of the sample data, it has been observed that at several spots, there is concentration of nugget values, some times as high as 2000 g/t. These freak high values do not persist either along the strike or in depth. There appears to be no rhythm or rhyme in the distribution and concentration of gold.

A careful analysis of the sample data of every level extending over all the five gold mines has revealed several nugget value spots. Nugget value spots are spots where gold is present in more than 50 g/t in the Champion lode. The table 16 provides a summary of the distribution of the nugget value spots along the strike (26,000 feet long) and depth (up to 10000 feet). The same data is shown in Fig.32 as histogram in which the distribution of nugget values at various depths is desplayed.

Fig.32 Histogram showing the distribution of nugget value (> 50 g/t) spots in the Champion lode

Nugget values

100 200 300 400 500 600 700 800 900 1000 1100

Depth in feet

1000 ______________(303)
2000 ______________ (439)
3000 ______________ (749)
4000 ______________ (725)
5000 ______________(1039)
6000 ______________ (566)
7000 ______________(504)
8000 _______ (213)
9000 _ (12)
10000 _ (5)

From Table 16 and Fig 32, it is apparent that out of 4628 nugget value spots, 3328 spots occur from surface to 5000 feet depth and the other 1300 occur between 5000 and 10000 feet depth. It means that more than 78% of the nugget values occur in the upper parts of the Kolar Gold Mines and less than 28% of the nugget values occur in the lower part.

TABLE 16

Showing the mine-wise distribution of Nugget values in the four out of five mines

Mine depth in feet	Length in feet																					
	Balaghat 3000'		Nundydroog 7000'						Oorgaum 3400'				Champion 3500'	Mysore Mine 9000'								
1000	39	38							3		13											
2000	6													16	14	44	15	13	61	13	33	
3000			10	56	78	41	22			6	56	39		40	99	89	41	64	9	30	61	73
4000			34	63	123	41			35	211	82	6	DATA	15	140	26	128	78	26	24	8	1
5000			217	55	14	103	12	5	149	222	99	58	NOT	1	20	15	33	3	3	49	6	
6000			34	11	3	43	35	32	85	51	155		AVAILABLE		4	20	15		50			
7000			3	2	13		7	16	113	112	136	8				31		8	78			
8000			5	2				1	4	12		110				33		55	6			
9000											3	5			29	24		28				
10000											2	3			4							

Distribution of Nugget value spots in different mines on the champion lode, numbers indicate the number of nugget value spots at each block of 1000' in strike length and 1000' depth.

Nugget value spot - spot with gold more than 50 gm/ton.

In Nundydroog and Mysore mines more than 82% of the nugget values spots are localised in upper part (above 5000' level) and the balance 18% is found in the lower levels. However, in the case of Oorgaum mine the percentage of nugget value spots are 55% and 45% respectively in the upper and lower parts.

Since the subject of nugget value spots has not been studied, the following tentative model has been proposed for the occurrence and formation of nugget values in the Champion lode deposit of epigenetic origin associated within Kolar Schist Belt which is an Archaean green stone belt. The following sequence of geological events is visualised.

First generation of fracturing in the host rock -Komatiite and introduction of quartz veins.

Second generation of fracturing in the brittle quartz veins gives rise to narrow and long fractures leading to introduction of gold and silver and secondary minerals giving rise to parallel or subparallel ore bodies leading to the end of normal gold mineralisation.

However in rare cases, the residual gold that will be still locked up in the auriferous chamber may find an escape due to building up of fresh pressures. Under such circumstances, the residual gold will be pushed upwards by the latent fluid pressure. As the gold bearing solutions or emanations rise upwards due to the plumbing action, which may act in several pulses, the quartz lode and the host rock offer only partial resistance. As a result fresh micro fractures are developed within the quartz wherever resistance is least. Twedle Haile (1989) who studied the fluid inclusion petrology of the Kolar Gold Mines concluded that the gold lodes at Kolar Gold Field were repeatedly fractured on a microscopic scale under hydrothermal conditions.

Micro fracturing takes place in the already fractured, mineralised and healed up quartz veins. Into such microfractures the residual gold from the fluid chamber will get injected as secondary deposition over the already existing gold deposition of first generation. Due to repeated pressure pulses, new microfractures will be generated into which the remnant gold will get concentrated by over crowding or overlapping which in turn gives rise to nugget values. Thus secondary and tertiary enrichment takes place in quartz veins at places wherever the first and second generation fractures are not fully healed. Apart from these simple factors, there may be several other more complicated factors, which must have synchronised to give rise to the nugget values.

The very fact that nearly 72% of the nugget values are concentrated in the upper part of the Champion lode, it suggests that the upper part must have provided more desirable conditions like reduced temperature and pressure leading to the microfracturing of the gold quartz lode and ultimately the deposition of secondary and tertiary generation of gold.

In the Kolar Gold Mines several samples of gold lumps (which may be also called nuggets) were recovered in the past. But unfortunately there are no records about their weight, size and the level or location from where it was collected. Plate 1(a, b, c, d and e) shows photographs of the some of the nugget specimens still preserved in the metallurgical department of Nundydroog mine. Pryor (1923) who examined the underground geology of Kolar Gold Mines made a special mention about the rich gold occurrence in the 35th level of Nundydroog mine. "The gold is found sporadically in breccia associated with rough open spaces in the Champion lode. In the other mines the vugs are rare. The breccia has been recemented by calcite after which gold has been deposited with tetrahedrite and chalcopyrite. In this breccia, gold has been very massive. Plates of gold as large as a man's hand and over 1/16th inch thick have been reported. This breccia has been irregular but has been followed up to 3600' level". In the past such nuggets were being preserved to be shown to visitors. Subsequently

PLATE

a. Gold nugget weighing 75 grams in secondary calcite

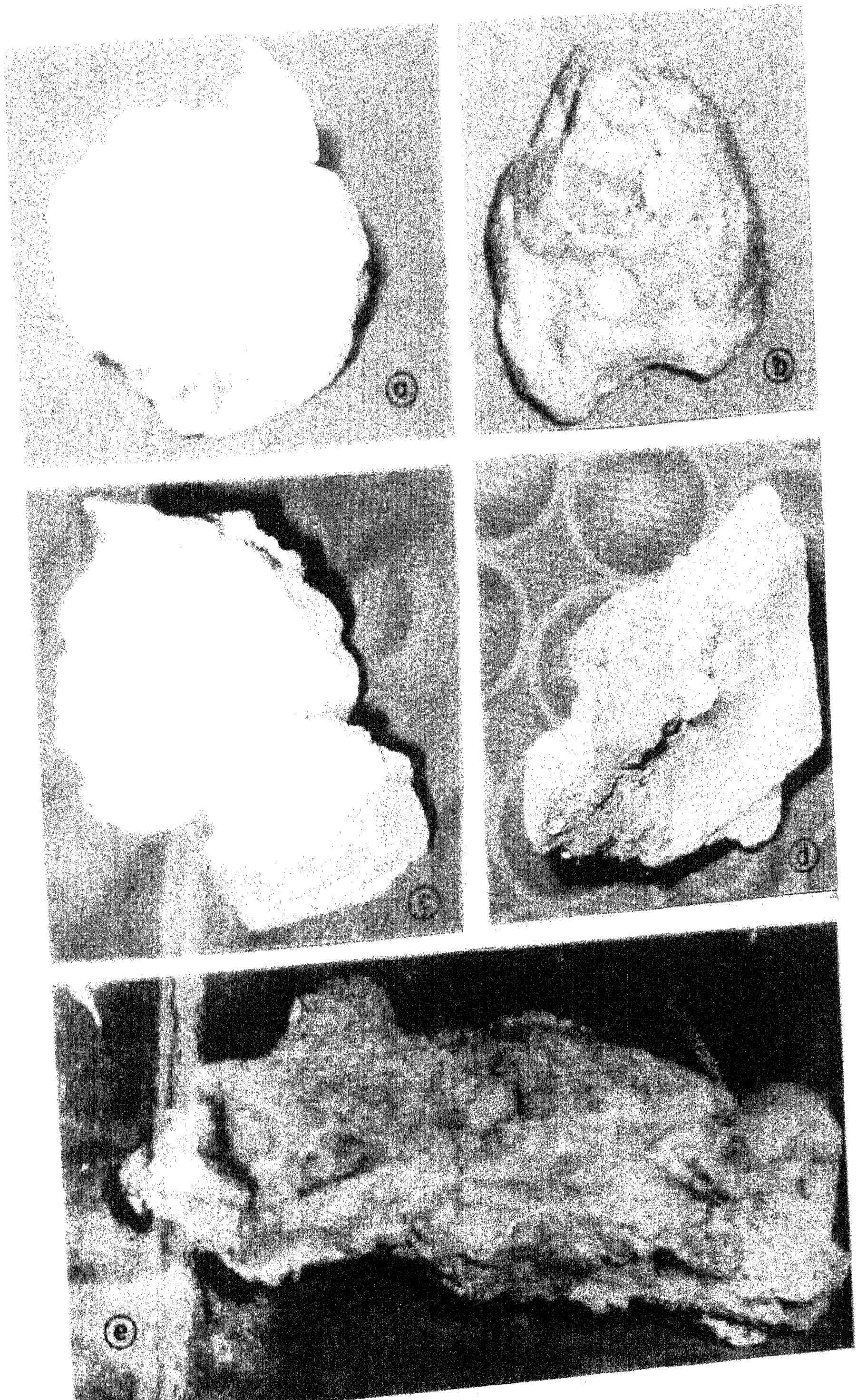
b. Gold nugget weighing 250 grams

c. Gold nuggets weighing 150 grams in secondary calcite

d. Gold nugget weighing 100 grams in fault breccia

e. Intricate veinlets of gold weighing 300 grams in quartz vein.

PLATE



during final stages of mining operations of the individual mines, most of these "nuggets" were smelted without appreciating its unique geological value. One small nugget weighing 275 gms is still preserved in Nundydroog mine mill. Thus the formation of nugget value spots due to microfracturing in the Kolar Gold Mines is another factor which accounts for high incidence of gold at several places throughout the length and depth of the Champion lode, although there are more nugget value spots from surface to 5000 feet depth and less below 5000 ft. depth.

4.7 Reduced Pressure and Temperature

Among the various geological factors, which induce mineral precipitation, the lowering of temperature and pressure is the most important one. Rock pressure increases with depth below the surface of earth. It is usually calculated as equivalent to the weight of column of rock above it. The pressure on any small area is transmitted in an outward flaring cone of diminishing intensity. The mineralising solutions at any place are subjected not only to the hydrostatic pressure but also to the driving force to over come the friction. It is universally known that in any conduit the steepest pressure gradient will be found at the greatest constriction. Similarly the moving ore bearing solutions may lose temperature because of their contact with colder wall rocks. The degree of loss of temperature is dependent on the volume of solutions moving past a unit area of wall rock and the amount of heat transmitted or absorbed during the chemical reaction between the moving solutions and wall rock.

Presence of relatively large openings and fissures above a constricted feeding channel favour steep precipitation.

In case of the Champion lode in the Kolar Gold Field the diminishing pressure and temperature must have played an important role in the enrichment of

gold in the upper levels where a large area is mineralised from surface to 5000' depth.

Estimates of temperature-pressure conditions for the formation of gold deposit have been made for many years utilising mineral intergrowths, thermal stabilities, pyrite - geothermometry, sphalerite decrepitation, isotope data and liquid inclusion studies. Boyle (1979) after reviewing the works of several investigators on the liquid inclusion studies relating to the gold deposits in Canada, USA and New Zealand attributed the formation of gold deposits under various temperature conditions. The results gave a very wide range as mentioned below:

Table 17. Showing the formation of gold deposits under various temperatures

(1) From 300°c - 380°C	:	For pregold mineralisation fluids
(2) From 420°C - 450°C	:	Gold mineralisation fluids
(3) From 170° C - 300°C	:	Post gold mineralisation vapour liquids.

From the recorded geothermal studies, Boyle (1979) conceds the great uncertainties in the liquid inclusion studies. It is obvious that much more sustained research is necessary on the geothermometry of epigenetic gold deposits in order to establish the true temperature ranges of gold deposition. According to him, the published works on temperature and pressure is very exhaustive and deals with temperature, pressure studies of the gold deposits at great depths in the bowels of the earth or on the upper crust of the earth. These figures show very wide variations. Obviously the gold deposition might have taken place at various places both in space and time due to the presence of (a) favourable structures, (b) appropriate solubility stage of gold bearing solutions and emanations and (c) a decrease of temperature and pressure. Thus a synchronisation of several geological factors is essential for gold deposition in which the role of reduced temperature and pressure is a key factor for epigenetic gold deposition.

According to Subramanyam et al (1991) the rock types of Kolar Schist Belt have undergone regional low-pressure amphibole facies metamorphism on the basis of mineral assemblages.

The metamorphism gradually increases towards the margins of the schist belt as well as in the deeper structural level in the south (Viswanatha and Ramakrishna 1981). Narayana Kutty and Anantha Iyer (1977) estimated a temperature of 600°C and at a pressure 3 to 5 K bar for the entire mineral paragenesis (quoted by Subramnyam 1991).

According to Lindgren (1933) the fundamental reason for deposition of ores in the epigenetic deposits in the upper crust is probably that metals were in solution in hot waters which during ascent gradually encountered conditions favourable for precipitation. First among these conditions is the decrease in temperature. On the basis of Lindgren's assumption, as the vertical space available for gold deposition in Kolar Gold Mines is very vast, a general fall in the grade of gold and petering out of the ore shoots in depth is seen. Lindgren (1933) cites the examples of gold quartz veins of California, Colorado, Cripplecreek and Ontario as formed due to decrease in temperature of ascending solutions in channels of circulation.

Underground temperature and pressure studies in the mines

It is a common experience that as we go deeper into the earth, the temperature and pressure increase due to geothermic and lithostatic gradients respectively. The theoretical geothermic gradient is 30°C for every kilometer depth up to Moho because of the presence of radioactivity found in the crust (Yakushova 1986). Similarly the pressure increases with depth at about 30 mpa (30.6 atmospheres) per kilometer depth mainly due to lithostatic confining pressure of the overlying rock (Philip Keerey et al 1990). Against this assumption

the actual temperatures and pressures recorded in the Kolar Gold Mines (Rao, 1980 and Gowd et al 1983) and in some of the Canadian gold mines in the States of Ontario and Manitoba (Herget 1980) are quite less (Tables 18-22). The reasons may be due to heterogeneity of rock composition and non-uniform structures prevailing within the unstable earth.

Table-18 The theoretical assumption and actual temperature recorded in Kolar Gold Mine

Depth (m)	Theoretical assumption temperature deg. C (YUKUSHOVA, 1986)	Recorded temperature in KGF deg. C (RAO, 1980)
SURFACE		
1000	30	Data not available
2000	60	Data not available
3000	90	65.5

Against the above theoretical assumption of temperature gradient, the actual gradient recorded in the Kolar Gold Mines (Rao 1980 and Issacson 1963) is shown in Table -19

Table – 19. Temperature gradients in Kolar Gold Mines

Depth in feet	Temperature rise by 1° F According to Rao (1980)	According to Issacson (1963)
Surface- 4000	for 196 ft.	Near surface for 166 ft.
4000 - 6000	for 133 ft.	Below 5000 ft. for 110 ft.
6000 - 8000	for 114 ft.	No data
8000-10000	for 107.5 ft	At 10,000 ft. for 150°F (spot record)

The above data confirms the steepening of the temperature gradient with depth although it does not support the theoretical assumption of 30° C rise for

every kilometer depth. According to B. Guttenberg (quoted by Yakushova 1986) the geothermal gradient does not remain constant for different parts of the earth. The extreme limit could be as high as 25 times due to difference in the tectonic conditions of the earth's crust and different conductivity of rocks. The highest thermal gradient of 150°C per kilometer depth has been registered in the State of Oregon (USA) with a step of 1°C for every 6.67 m. The lowest gradient of 6°C per kilometer depth has been recorded in South Africa with a step 6°C for every 167 m. The highest values obtained in Oregon (USA) is associated closely with tectonic mobile zone and the lowest values obtained in South Africa is associated with ancient stable crystallines. These findings confirm that the theoretical assumption of an increase of 30°C per kilometer depth can not be used for specific purposes.

Pressure gradient studies in Kolar Gold Mines

Gowd et al (1983) have determined the vertical stress measurements in the Kolar Gold Mines (Table-20) derived from hydro fracture data.

Table – 20. Vertical stress readings at different depths in the Kolar Gold Mines

Depth (m)	Average insitu vertical stress (mpa)	Remarks
590	11.2 (8)	20th L Nundydroog Mine
1044	22.5 (8)	40th L Nundydroog Mine
1119	12.1 (6)	40th L Champion Mine
2128	17.4 (5)	74th L Champion Mine
2874	34.6 (6)	100th L Champion Mine

(Note: The figures in the brackets indicate the number of readings)

According to Gowd et al (1983), these results demonstrate that the vertical stresses in Kolar Gold Mines is only 35-70% of the overburden pressure because the rocks in the vicinity of the test areas in the mines have been destressed in the vertical direction. This further supports the view that the over burden pressure in Kolar Gold Mines is in a state of equilibrium, perhaps due to its transfer to other places far away from mine workings.

The underground temperature and pressure studies in the Kolar and Canadian gold mines (Table-22) although do not confirm to the theoretical assumptions, they do confirm the commonly known observation that both the temperature and pressure increase with depth.

For the present study it can be concluded that the reduced virgin temperature (about 35°C) and pressure (about 40 mpa) greatly facilitated higher precipitation of gold in the Champion lode in the upper level of Kolar Gold Mines.

Pressure gradient studies in the Canadian Gold Mines

Herget (1980) compiled and analysed the data on the regional stresses in 9 gold mines in Canada. His findings (Table-21) reveal a wide fluctuating pressure measurements not only at the same depth but also in the same mine.

Table – 21 Pressure readings in 9 gold mines of Canada

Depth (m)	Pressure (mpa)	Name of the Mine
335	10.3	) Nordic Mine, Ellot Lake
307	11.0	) Denison Mine, Ellot Lake
701	17.2	) " " "
366	16.3	) Mcleod Mine, Nawa
366	23.5	) "
479	19.4	) "
570	28.6	) "
570	22.1	) "
570	23.9	) "
570	14.7	) "
488	13.4	) Kidd Creek Mine, Timmins.
732	43.9	) "
853	20.9	) "
853	23.6	) "
610	26.8	) Thomson Mines, Thomson.
1219	97.3	) "
457	17.8	) Birchtree Mine, Thomson
838	16.1	) "
1148	34.1	) Madson Mine, Red Lake
701	19.1	) Creighton Mine, Sudbury
701	22.0	) "
701	18.8	) "
1219	38.5	) "
1219	18.2	) "
1219	40.1	) "
1707	87.6	) "
1707	102.2	) "
1707	53.6	) "
2073	124.7	) "
2134	31.7	) "
2134	37.4	) "
2134	43.4	) "
2134	49.9	) "
1227	38.9	) Onaping, Ontario
1227	33.3	) "
1227	47.1	) "

Table – 22. Comparative pressure measurements (mpa) in Canadian and Kolar gold mines at various depths. Figures in the brackets indicate the number of readings

Depth (m)	Pressure (mpa)	
	Canadian mines	Kolar mines (on Champion lode)
307	11.0	
335	10.3	
366	19.9 (2)	
457	17.8	
479	19.4	
488	13.4	
570	22.4 (4)	
590	-	11.2 (8)
610	26.8	
732	43.9	
701	20.0 (3)	
838	16.1	
853	22.2	
1044	-	22.5 (8)
1118	-	12.1 (6)
1148	34.1	
1219	29.0 (3)	
1229	39.8 (3)	
1767	48.3 (3)	
2073	124.7	
2128	-	17.4 (5)
2134	41.8	
2874	-	34.6 (6)

4.8 Damage due to pegmatites

Pegmatites have an inbuilt notority in causing severe damage to any ore body wherever they occur in a mineralised province. They are essentially residual magmas, which are injected into the earlier consolidated portion of the enclosing rock. The fluidity and melting point of pegmatites are of great importance in allowing them to soak and penetrate the schistose and fissile rocks encountered on their way. The pegmatites occur as dykes or as irregular masses. Probably their irregularities can be explained by the sudden and explosive action by which they make room for themselves and hold on to the cavities and fractures until their substance is crytallised. Bichan (1947) opined that "the pegmatite intrusions are spatially associated with the gold bearing quartz and comagmatic emanations are not far removed in age".

In the Kolar Gold Field area, there are no significant outcrops of pegmatites along the entire 8 km length mining area. However, those which are encountered in the underground workings are acidic in nature and contain essentially quartz and feldspar with accessory tourmaline. The underground occurrence of pegmatites are plotted on the vertical transverse section of the Kolar Gold Mine (Fig. 10) which depicts its distribution both along the strike and in depth. A cursory examination of this section highlights the following details mine wise from North to South.

In the Balaghat mine, which is the northern most, three pegmatite veins occur, each about 25-30 feet wide. The first one occurs between 2300' - 3000' depth and the second one between 2500' - 4000' depth and the third one between 3200'-4500'.

In the Nundydroog mine, the pegmatites occur quite extensively and also irregularly from 5500' - 8000' depth as "roots" of the champion lode.

In the Oorgaum mine, the pegmatite occurs extensively and irregularly at two horizons. The first one is between 5700' - 8300' depth and the other between 8800' - 9800' depth.

In the Champion mine the pegmatites occur at the places between 5200' – 7800' and between 8800' – 8900' depth.

In the Mysore mine which is the southern most one, the pegmatite occurrence is rather insignificant and occurs only for about 300' extent in the 6200' and 8000' levels.

Generally, the pegmatites because of their intrusive and irregular nature has cut through the Champion lode and the enclosing host rock at several places and has assimilated the auriferous lode resulting in the total loss of lode. Bichan (1947) who studied the pegmatite in the Nundydroog mine opined that all pegmatites observed in close proximity to vein quartz have been injected along contacts or obliquely across the quartz lodes. Normally the pegmatites are barren but in the vicinity of auriferous lodes, the pegmatite has incorporated a certain amount of gold bearing quartz.

Burdun (1947) while studying the petrology of Kolar Gold Field has identified the following minerals in pegmatites of Nundydroog mine based on thin section studies:

> Orthoclase, microcline, albite, oligoclase, quartz, spodumene, sericite, muscovite, epidote, grossularite, tourmaline, beryl, apatite, rose quartz, molybdinite, pyrrhotite and gold.

The following are the gold values recorded by him from samples of pegmatites collected at various depths

Table-23. Showing the gold values in pegmatites at various depth in Nundydroog mine

Depth (ft)	Width of Pegmatite (inches)	Gold values in dwt = 1.71 g/t
3430	9	Trace
4000	20	200
4050	46	20
4725	45	69
4800	8	35
5000	14	25
5825	10	Visible gold

Since the pegmatite intrusives are post gold mineralisation, it is obvious that these gold values can be attributed to the assimilation of gold bearing quartz by the invading pegmatite. The earlier British mining engineers used to treat pegmatite as waste material and were throwing it out along with the waste rock.

The loss of lode below 5000' depth from the two rich shoots in Champion mine namely the "southern ore body" and "Glen ore shoot" is quite significant. Fig.33 depicts the damage caused to Glen ore shoot by pegmatite intrusion.

As an example, a rough estimate of the loss of gold between the 91 and 93 levels of the Glen ore shoot due to assimilation by a pegmatite vein, which is 1000' long and 100' deep, is shown below:

a) Length of pegmatite = 330 m
b) Height of pegmatite = 33 m
c) Width of pegmatite (assumed) = 1 m
d) Specific gravity of quartz = 2.7
e) Gold content of the ore body = 25 g/t
= 33 x 1 x 2.7 x 25
= 735075 gms

f) Gold lost due to intrusion of pegmatite = 735 kg.

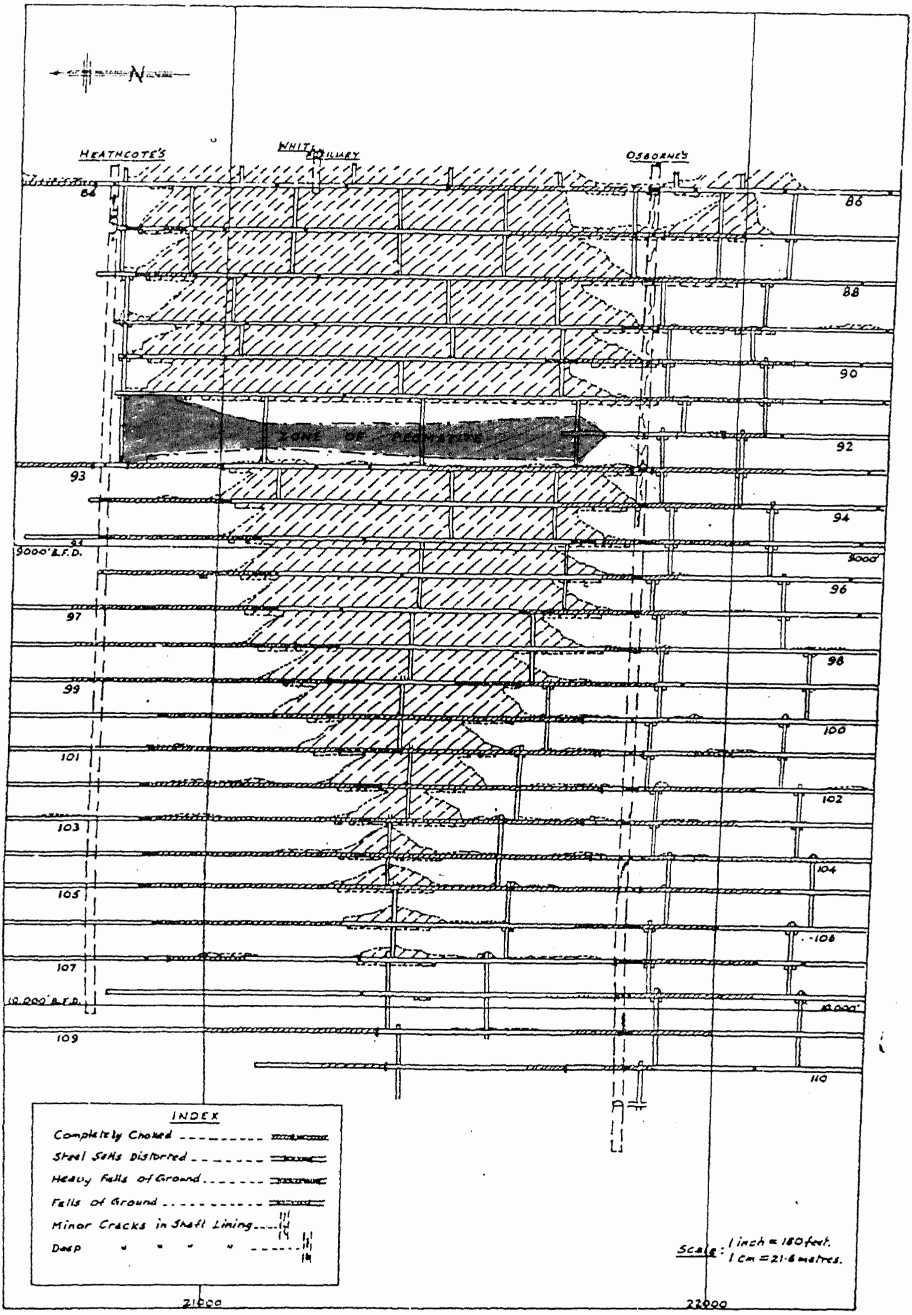


FIG. 33: DAMAGE CAUSED TO GLEN ORE SHOOT BY PEGMATITE INTRUSION

This 735 kg of gold at the current price of about Rs.400/gm is valued at Rs. 294 lakhs.

In contrast to this, the loss of gold due to pegmatite intrusion in the upper parts (from surface to 5000' depth) of Kolar Gold Mines (Fig 10) is quite insignificant because there are only three small pegmatite occurrences in the Balaghat mine. In the other 4 mines i.e. Nundydroog, Oorgaum, Champion and Mysore mine there are no pegmatites in the upper levels. The effect of the pegmatite veins on the lode in Balaghat mine is very minimal. In general, as can be seen from the Fig 10 the pegmatite occurrences are mostly confined to the deeper portions of the lode. Therefore, the loss of lode due to pegmatite intrusion is minimal in upper levels whereas it is considerable in deeper level of the Champion lode. As can be seen from vertical transverse section the pegmatite distribution in the bottom levels occur as "roots of champion lode". Bichan (1947) in his prophetic words had predicted that "the Champion lode will be found to grade from a predominantly quartz filled system of veins into a pegmatite as deeper horizons are attained".

For the purpose of our present study, the near absence of pegmatites in the upper portions (up to 5000' depth) of the Kolar Gold Mines has been a major geological significance in preserving the rich gold values from being assimilated by the pegmatite intrusion. Perhaps it is nature's gift to Karnataka that the invading pegmatite had lost its steam and driving ability to reach the upper horizons. As a result the damage caused by the pegmatite to Champion lode has been confined to only the bottom section of the mines, where already the Champion lode has shown evidence of its natural diminution in size.

4.9 Weathering

"As land surface is worn away in regions where conditions are unfavourable for solutions, gold tends gradually to become concentrated at the surface"

-W.H. Emmons.

During the last 2600 million years (Radhakrishna, 1994) the gold bearing rocks and the Champion lode have been subjected to various agents of weathering. According to Chernyshev et al (1991) weathering greatly affects rock fractures resulting in the expansion and giving rise to new fractures. Rock mass heterogenetics intensify in the course of weathering. As a result the zone of weathering has wide fractures filled with clayey weathered products. The weathering spreads from surface along major fractures and then along minor fractures.

As fractures of earlier generation get filled up, successive generation of fractures get superimposed on each other and ultimately the fracture system becomes asymmetrical and chaotic. This leads to disintegration, decomposition of the gold bearing quartz and the enclosing host rock. The gold particles on being released from quartz lode migrate downward at places where the gradients are low and along various openings due to descending meteoric waters and gravity.

The gold gets deposited due to oxidation and other related weathering processes of the host rock and it has a tendency to get enriched in near surface due to the removal of soluble gangue minerals. The gold particles because of its high specific gravity, move slowly downwards. To a large extent this is influenced by the nature of host rock, degree of fracturing of the host rock and quartz lode,

climatic conditions of the area, position of the water table and the type of gold deposit.

In the Champion lode, the native gold is relatively inert and hence it moves into the oxidised zone with out undergoing any chemical change. However the gold particles during migration may undergo size reduction.

According to Boyle (1979) the chemistry of surface and sub-surface waters have a direct bearing on the chemical action on rocks that releases gold in the oxidising zone. Clay minerals and gelatinous silicate complexes, which tend to concentrate gold in gouge and other clay minerals along fractures, will also tend to concentrate gold in oxidising zone.

According to McKinstry (1948) gold is most resistant to weathering as a result particles of native gold accumulate in fractures and voids in the rock and often produce spectacularly high assay values at the immediate surface. In addition, the chemical leaching of associated materials tends to concentrate the gold. Most enriched gold present in the oxidised zone is due to removal of other elements. Thus gold enrichment often takes place more by reduction of volume of the quartz vein and host rock than by addition.

According to Bateman (1948), when ore deposits are exposed by erosion they undergo weathering along with the enclosing rock. The surface water oxidises many ore minerals and yield solvents that dissolve other minerals and as a result many valuable minerals are leached out. The effects of oxidation may extend far below the oxidation zone leading to deposition of oxidised ore just above the water table and also below the water table giving rise to very high anomalous gold contents.

According to Mann (1998) the oxidising zone extends upto water table and often upto 100 feet below the water table depending upon the fluctuations of

the water table during the geological past. Fig. 34 is a generalised model for an oxidised gold deposit where oxidation can take place both above and below the water table. Mann (1998) who studied the Golden Web Deposits in Western Australia has recognised four zones in the weathered zone and their relative gold contents are found to be high compared to the primary ore. In the Hutti Gold Mines of Karnataka according to Raju (1996) when mining operations were resumed between 1902 - 1918, the company mined 3,78,000 tonnes of ore and recovered 7370 kg of gold at an average grade of 19.5 g/t. In the opinion of the author this 3,78,000 tonnes of ore must have been mined from the weathered zone to recover nearly 20 g/t as against 5 g/t now being mined for the last 50 years from the primary ore.

In the Kolar Gold Mines area old workings are spread throughout the 8 km. length of the Champion lode starting from the Balaghat mines in the north to Mysore mines in the south (Fig.9). Some of the old workings are more than 250' deep as indicated in the section (Fig.12).

Gupta (1980) mentioned that prior to the arrival of M/s John Taylor & sons in 1880, the local natives and ancient people had mined 3,36,000 tonnes of ore at 18.5 g/t and had recovered 6.2 tonnes of gold. The basis for this is not indicated. The early miners with crude implements and with no geological knowledge could go up to about 20 m depth only and abandoned their operations because of their inability to cope up with the heavy inflow of surface waters and also their inability to provide suitable ground support to the highly decomposed wall rocks. This 20m depth corresponds to the upper horizon of the oxidised zone, which contained gold fairly in high concentration compared to the primary ore, which lies below the oxidised zone.

Between the years 1881-1900 after the arrival of M/s John Taylor & Sons, the mining operations in the 5 mining blocks on the Champion lode i.e. Balaghat, Nundydroog, Oorgaum, Champion and Mysore mines were systematically

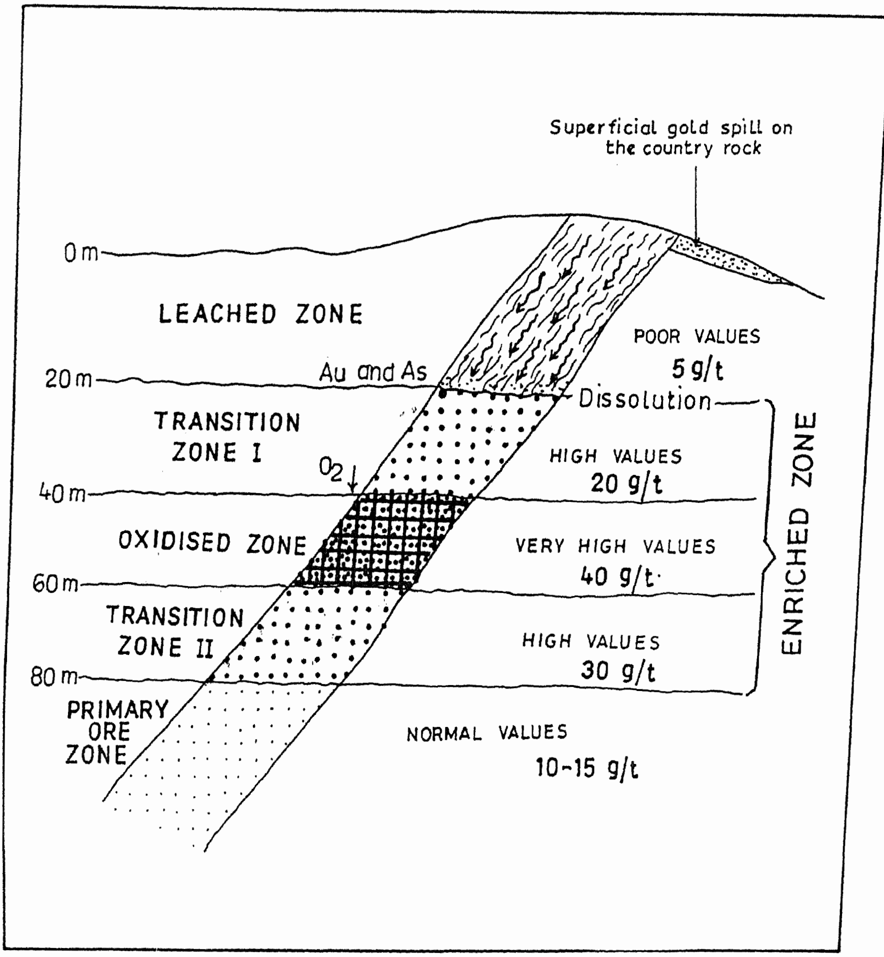
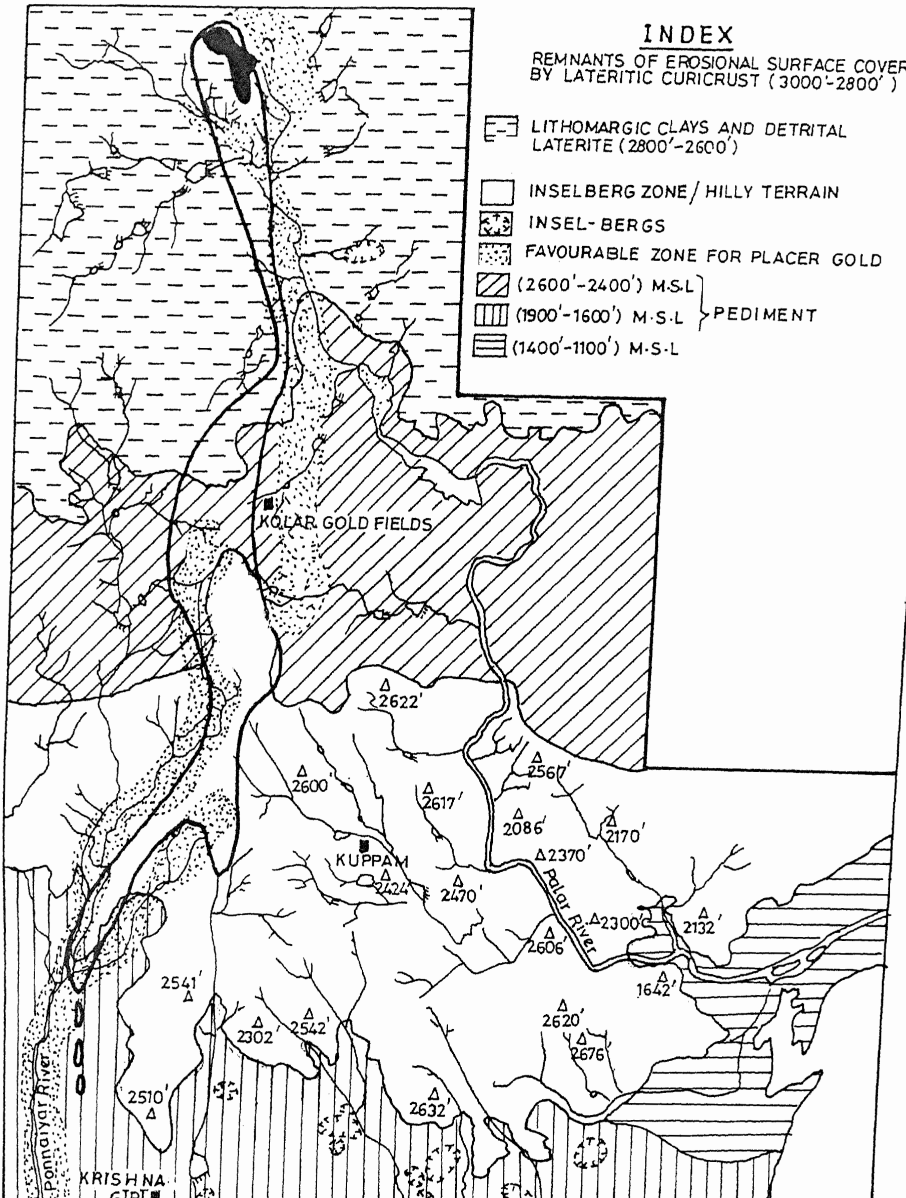


FIG-34: AN IDEALISED PROFILE OF WEATHERED ZONE OF CHAMPION LODE SHOWING GOLD VALUES IN DIFFERENT ZONES

streamlined and important surface shafts were sunk, metallurgical plants were established in all the 5 mining blocks. The mine workings were extended below the oxidised zone by providing timber supports to the highly decomposed wall rocks. During this 20 year period although only 2,80,000 tonnes of ore was crushed, the yield of gold was 95800 kilograms of gold at a fabulous grade of 44.5 g/t which is perhaps the highest grade ever mined on the Champion lode (Table 8). The major factor responsible for this high grade is undoubtedly the leaching of gold from the Champion lode and host rock to give rise to gold of secondary enrichment. The gravity, the dip of the ore body the percolating surface waters and widened openings of the original fractures without any barriers are the likely other factors which have also collectively contributed to the high enrichment of gold in the lower portions of the oxidised zone.

From the above it is evident that weathering has played a unique role in enriching gold in the oxidised zone of the Champion lode which must have taken place over a period of several millions of years. Normally the weathering coupled with good drainage and transport give rise to important placer gold deposits. But according to Ramakrishna Reddy (1980), who made geomorphological studies for locating favourable zones for placer gold concentration in the upper reaches of some river basins in parts of Karnataka, Andhra Pradesh and Tamil Nadu, reported the absence of any placer deposits (Fig.35). He further opined that the original topography of precambrian period must have suffered an upliftment, which obliterated all traces of placers. Obviously all the gold that was released during the past millions of years must have partly migrated into the bedrock by gravity and partly carried down by rivers into Bay of Bengal. As a result the present topography in the neighbourhood of Kolar Schist Belt is devoid of any placer deposits.

Another feature of weathering is that although the quartz veins in Kolar Gold Field are about a meter wide, the old workings are more than 10-15 meters wide. This is perhaps due to the spill over of the secondary gold in the oxidised



Source: G S I (1980)

FIG-35: GEOMORPHOLOGICAL MAP OF AREA AROUND KOLAR SCHIST BELT SHOWING FAVOURABLE AREAS FOR PLACER GOLD

zone from the narrow quartz lode zone into the highly decomposed host rock which also offered suitable openings for migration of gold downward by gravity and moving surface waters. This prompted the earlier prospectors to open up several pits along the entire 8km length of the Champion lode (Fig.9). In contrast to this the later mining operations have proved that the Champion lode is not a continuous ore body. According to the annual reports of Balaghat and Nundydroog mines the earlier miners who reopened some of the old workings realised that gold values petered out below 10 to 15 meters and hence they abandoned the operations. This can be explained by the fact that such old workings are really not on the lode but were on the secondarily enriched adjoining weathered country rock.

From the above analysis it is evident that weathering is one of the important geological factors in enriching gold from surface to the lower layers of the oxidised zone. Therefore the gold prospectors should understand the limitation of this factor while assessing the gold deposits in new areas.

The present study leads to a thumb-rule, which can be stated as "**If the weathered zone carries low gold values, it is unlikely that the primary ore carries any better values**".

CHAPTER-5

CONCLUSIONS

CHAPTER-5
CONCLUSIONS

1. The Champion lode is 8 km long on surface and tapers to 0.5 km at 3.2 km depth, giving it a funnel shape. From surface to 1.5-km depth, the average length of the Champion lode is 7 km, but from 1.5 km to 3.2-km depth the average length of the Champion lode is 2 km only. Thus the extra 5km length of Champion lode in the upper part of the mines has contributed more gold.

2. The Champion lode between 2.5 to 3.2 km depth looks as a neck or vent. Contrary to the geological belief that gold values peters in depth, the Champion lode continues to be rich even at 3.2-km depth. This is due to the inability of the gold bearing solutions and emanations to rise above the vent during the waning periods of tectonic activity resulting in the collapsing and slumping of the auriferous solutions into the vent itself which in turn resulted in high gold values in the vent region.

3. Fracturing in its various manifestations is responsible for gold concentration in the Champion lode at several places.

    i) Due to gravity there is a high concentration of gold along the footwall of the Champion lode.

    ii) During the ascent of the auriferous solutions, the footwall and the hanging wall contacts of the Champion lode acted as barriers and prevented the gold from spilling into the host rock. Thus there is concentration of gold both along the footwall and hangingwall contacts of the Champion lode.

iii) At shallow depth, the Champion lode is dipping at low angle. During the course of the formation of the Champion lode, the hanging wall block of the Champion lode developed a secondary fracture during its settling on the footwall block. This secondary fracture was also later filled by minor quartz veins and auriferous solutions. This has given rise to the Mundy's lode in the central part of the Kolar Gold Mines. The presence of Mundy's lode is another factor in favour of more gold concentration in the upper parts of the Kolar Gold Mines.

iv) The sharp bends of the Champion lode both along the strike and dip, is enriched with higher gold values. This can be compared to the concentration of placer gold along the bends of a stream in an auriferous tract.

v) The tension fractures originate in depth and travel towards the surface. With diminishing pressure, the tension fractures become weak and form "horse -tail" pattern resulting in the formation of 3 to 4 en-echelon type of parallel lodes. This is responsible for an over all enrichment of gold in the upper levels of the Kolar Gold Mines.

vi) The Champion lode is made up of several fissure filled quartz veins. These fissures when they meet give rise to zig zag type of fractures or false fold like structures in the shape of V, N, W and Z. These fold like structures are responsible for doubling, tripling or more of the gold lodes in an unit area leading to high concentration of gold both in the upper and lower parts of the Kolar gold mines.

vii) The low angle dip of the Champion lode in the upper part of (up to 1600 m) the mine has provided a better receptacle for retention of gold along the footwall.

4. Surface and underground geological mapping has indicated that the Champion lode is clearly hosted in the komatiite. Recent geochemical studies by several researchers also confirm that the source of gold for the Champion lode is the enclosing volcanic sequence of rocks. This idea is further substantiated by the reported presence of high background gold values in the greenstone belts all over the world. Evidence for the presence of gold in komatiite ranging from 0.2 to more than 20 g/t has been obtained by sampling of the komatiite around the Champion and Mundy's lodes in the shallow levels of Champion and Mysore mines. This confirms that the komatiite in the Kolar Gold Mines is both a host rock and source rock for gold. This calls for a fresh study of the komatiite of the Kolar Gold Field preferably by Geological Survey of India. Besides its economic interest this study is likely to have great implications of world wide interest about komatiite being a source for precious metals.

5. All the faults in the Kolar Gold Mines are post mineralisation. However, in the Mysore North Fault zone, there are two important ore shoots located from surface to 1000 m depth. This unique occurrence of ore shoots in fault zone is due to the drag suffered by the Champion lode during the shearing effect of the Mysore North Fault. Thus the presence of two "fault - drag - ore shoots" in the Mysore North Fault zone has contributed to higher concentration gold in the upper parts of the Kolar Gold Mines.

6. High gold values (50 g/t and above) are seen scattered throughout the length and depth of the Champion lode. Although the gold distribution of Champion lode is highly erratic, it has a definite vertical pattern. An analysis of the sample data suggests that 78% of high gold values occur in the upper parts of the mines and only 22% occur in the lower part. These high values give a nugget effect. Whenever fresh pressure is built up in the auriferous chamber it gives rise to microfractures of second generation into

which gold will be injected by repeated pulses as secondary deposition. Thus crowding and overlapping of gold in these microfractures has taken place leading to nugget effect.

7. The hot auriferous solutions from the deep seated source during its ascent, deposited gold and other minor metals in fractures on encountering suitable conditions such as reduced temperature and pressure in the upper parts of the Kolar Gold Mines. The temperature and pressure gradient studies in the Kolar Gold Mines and in some of the Canadian Gold Mines do not agree with the theoretically accepted gradients. Both in the Kolar and Canadian Gold Mines, although the gradients are low, there is a definite increase in temperature and pressure with depth.

8. There are no prominent outcrops of pegmatites in the Kolar Gold Mines area. However in deeper parts the pegmatites appear in the northern and central part of the mines. The pegmatites have assimilated vital parts of the Champion lode wherever they have intruded leading to loss of valuable gold. The absence of pegmatites in the upper levels of the mines is in a way responsible for retention of gold in the upper levels, which in turn has contributed indirectly to the enrichment of gold in the upper parts of the Kolar Gold Mines.

9. Since the champion lode was formed in the greenstone belt of the Kolar Schist Belt, (2600 m.y.) the Champion lode has been subjected to various agents of weathering. Because of poor surface gradient, the gold particles, which were released from Champion lode, migrated down and enriched the weathered zone of the lode.

From the above conclusions it seems possible that the Archaean vein type of gold mineralisation of the type in Kolar Schist Belt may start the beginnings of their formation from the processes of accretion of contrasting terranes along a

suture zone formed by mantle derived komatiite and other basic rocks, mobilising the metallic gold with them, which moved into upper levels aided by the magmatic fluids into the fractures developed during tectonic disturbances and ultimately gave rise to vein type of deposits. In this scheme of mineralisation, the present effort involves the identification of the causes of gold concentration at various loci of the Champion lode of the Kolar Schist Belt. It is hoped that this work may lead for greater research into the mysteries of gold concentration in the greenstone belts all over the world.

From the discovery of new gold deposits during the last two decades, it can be inferred that the Archaean greenstone belts which are considered as the best host-rock for gold, is slowly losing its rank to younger tertiary rocks. The future gold exploration activities shall target unconventional sites such as Pacific Rim Countries, Subduction zones resulting from plate tectonics, Sites of intraplate volcanic activity in the Hawaiian Islands in the central Pacific where submerged seamounts are abundant. The marine black shales and red muds all over the world have already been recognised as possible new source of gold for future generations.

The geophysics, geochemistry and metallurgy will have a larger role than the conventional geology in the coming decades in identifying and reassessment of potential new gold resources. A challenging role awaits the metallurgist in treating and recovering gold from the already known low-grade gold ores, which lie scattered in several parts of India. The present low gold price in the international market does not permit economic exploitation of these low-grade ores. Therefore the known gold deposits have to be re-examined and reassessed in the light of the identified processes of localisation of gold to meet the ever increasing demand.

REFERENCES

REFERENCES

ANANTHA IYER G.V. AND VASUDEVA MURTHY A.R. 1967 : Geology and Geochemistry of Kolar Gold Fields and the origin of gold quarts veins in Dharwar of Mysore : Symposium on Upper Mantle Project, Hyderabad, pp. 231 - 238.

ANANTHA IYER G.V. AND VASUDEVA MURTHY A.R. 1976 : Metamorphism, Geochemistry and Mineralisation in the Precambrians of Kolar : Geological Survey of India, Misc. Publication 23 (2), pp. 596 - 614.

ANANTHA IYER G.V. AND VASUDEV V.N. 1979 : Geochemistry of the Archaean Metavolcanic rocks of Kolar and Hutti Gold Fields, Karnatka, India, J.G.S.I, V. 20, pp. 419 - 432.

ANANTHA IYER G.V., VASUDEV V.N. AND JAYARAM S 1980 : Rare earth elements Geo-chemistry of metabasalts from Kolar and Hutti gold bearing volcanic belts, Karnataka craton, India, J.G.S.I., V.21, pp. 603 - 608.

ATABEK'YANTS, K. 1981, Endogenous halos of Kolar Gold Field and their utilisation for prospecting, United Nations Technical report submitted to BGML.

BALAKRISHNA, S. AND RAJAMANI, V. 1987 : Geochemistry and petrogenesis of granitoids around the Kolar schist belt, South India : Constrains for the evolution of the crust in the area. J.G.S.I., V.95, pp. 219 - 240.

BALAKRISHNA, S. HANSON, G.N. AND RAJAMANI, V. 1988: Geochemistry of amphibolites of the Kolar Schist belt, Deep continental crust of S. India, pp. 9 -12.

BALAKRISHNA, S., RAJAMANI, V. AND HANSON. G.N. 1989 : Geochemistry evidences for multiple mantle source for 2.7 G.A. amphibolites of Kolar. 28th International Goelogical Congress, Washington D.C. Abstracts, July 9-19, 1989.

BATEMAN, A.M. 1948. Economic Mineral deposits, pp. 243 - 245.

BICHAN, W.J. 1947, Structural Principles Controlling the occurrence of ore in the Kolar Gold Field, Eco. Geo. Vol. XLII, pp. 93 - 135.

BLE'S, J.L., AND FEUGA, B. 1986 Fracturing In Geology: General Tectonic Concepts, Chapter 4, pp. 67 - 90, North oxford Academic publication Essex, Great Britain.

BOYLE, R.W. 1979, The Geochemistry of gold and its deposits, Geological Survey, Canada, Bulletin 280.

BOYLE, R.W. 1985, Final Report on Gold Exploration in Kolar Gold Fields, U.N. Project IND/82/014, pp 1-10.

BRUCE FOOTE R, 1882 : Notes on a traverse accross the gold fields of Mysore : Rec. Geological Survey of India, 15(4), p 191 - 201.

BURDON J.C. 1947 : Petrology of the Kolar Gold Field : K.G.F. Mining & Metallurgical Society Bulletin 13.66, pp 119 - 201.

BURDON J.C. 1948 : Discussion on petrology of Kolar Gold Fields; KGF Mining & Metallurgical Soceity, Bulletin 13.67.

CALLENDER R.M. 1990, Gold in Britain Gold spear (U.K.) Ltd. Beaconsfield U.K.

CHERNVSHEV S.N. AND DEARMAN W.R. 1991. Rockfractures, pp 41-65 (Translated from Russian by GB MIROVSKY, Published by Butter Worth Heineman, UK.

CLIFF OLIVER 1974: Weathering and land form, Macmillon Eduction Press, Hamshire, UK.

CURTIS L.C AND RADHAKRISHNA B.P. 1995 (Hutti Gold Mine into the 21st Century, Mineral Resources of India, Geo. Soc. India, pp 122

DAVID GORTFRED, JACK J. ROWE AND ROBERT I.TILLING 1972: Distribution of gold in igneous rocks U.S.G.S. Professional papers No.727, pp 1-33.

DERONDE, C.E.J., DEWIT M.J. AND BRAY C.J., 1992: Shear zone related Au-quartz vein deposits in the Barberton Greenstone belt, South Africa, Field and Petrographic charecteristics, Fluid properties and light isotope Geochemistry, Eco. Geol.Vol 87, pp 366-402.

DHRUVA RAO B.K. AND SUBBARAMAN J.V. 1985: computer applications and Mathematical modelling for locating possible undiscovered ore bodies in Kolar Gold Mines, Karnataka, India, UN Inter-regional seminar on gold exploration and development, Bangalore, pp VII.1.1 – VII.1.47.

DIWAKARA RAO V. VENKATANARAYANA B AND RAMANA Y.V. 1976: Geochemistry of sub surface hornblende rocks from Kolar and Archaean crustal composition of peninsular shield - J.G.S.I, 17, pp 245-251.

DIXIT R.L.N. 1980 : Scheelite mineralisation in the Kolar Gold field. Seminar on Recent trends in gold mining practice - BGML, pp 166-177.

DUTTA A.K. AND SEN G.R. 1963, Generalised Geological history and petrology of the basic and ultrabasic rocks of Indian Precambrian shield, Geological Survey of India, Memo. 100, pp 3-35.

EMMONS W.H., 1936, Gold Deposits of the World, Mc Graw Hill Newyork.

EVANS, J.L. 1985: UN Project IND/82/014 final report on gold exploration in Kolar Gold Field (December, 1985)

EMILIANI CESARE, 1997, Planet Earth, Cosmology, Geology and the evolution of life and environment, pp.406

GENKIN A.D., SAFONOV YU.G., RADHAKRISHNA B.P., KRISHNA RAO B, VASUDEV V.N. AND DEB M., 1981: New Data on the mineralogy and geochemistry of Kolar Gold Field, India, Geology and mineral resources of Precambrian platforms : IV Indo-Soviet Symposium of the earth science, Moscow, Abstracts.

GERAND BUSSIAN AND MARE LABLANE 1987: Gold in Mantle peridoties from upper Proterozoic ophilites in Arabia, Mali and Maraco, Eco. Geol. Vol.82, pp 2091 - 2097.

GHOSAL A, 1983: Operations Research Project on Gold mineralisation in Kolar Gold Field, Group III Report.

GOKUL A.R., MUKHERJEE M.M. AND NATARAJAN W.K. 1980: Nature of gold mineralisation in South Kolar Schist Belt. Seminar on recent trends in Gold Mining Practice, BGML, pp 119-121.

GOLD BOOK - GUIDE BOOK 1988 - Minobras Mining Services, PB 262, Dana Point, California, U.S.A.

GOLDIE R. (1985): Lithostratigraphy and distribution of gold in the South Central Abitibi belt of Quebec Geology of Canadian gold deposits, CIM special volume 24, pp 15-26.

GOVETT M.H AND HARROWELL M.R. (1982): Gold World Supply and Demand, Australian Mineral Economics (P) Ltd. Sydney.

GOWD T.N. AND RUMMEL F. (1983), In-situ stress measurements by Hydrofracturing in underground mine of Kolar Gold Field, Indo-German Collaboration Project. Report submitted to BGML pp 1, 2, 51, 52

GROVA D.L. PHILLIPS G.N, HO SE AND HANDERSON, G.N, (1982): The nature genesis and regional controls of gold mineralisation in Archaean Greenstone belt of W. Australia. Gold 1982.

GROVES T.L. DEWIT M.J., DANN J, 1995: Wet Komatiites and Archaean Mantle conditions, Pre cambrian 95, Abstracts No.10.40.

GUPTA P.D. 1980: The past 100 years and the future of Kolar Gold Mines. The B.G.M.L. centenary souvenir, pp 1-6.

GUPTA R, AND SESHADRI C.V. 1996: The Booming Demand for Gold in India - Asian Gold Congress, 1996, Honkong.

GROVES D.I, PHILLIPS G.N, HO SE, HENDERSON C.A, CLARK M.E., AND WOAD G.M., 1982: Controls on distribution of Archaean Hydrothermal gold deposits in W. Australia, Gold 82, pp 689 - 709.

HAMILTON J.V. AND HODGSON C.J. 1986: Mineralisation and structure of the Kolar Gold Field, India. Proceedings of Gold'86 symposium, Toranto, pp 270-283.

HANSON G.N., KROGSTAD E.J. AND RAJAMANI V. (1988): Tectonic setting of the Kolar Schist Belt, Karnataka, India, Deep continental crust of South India, J.G.S.I. V.31, pp 40-42.

HATCH F.H. (1910), the Kolar Gold Field being a description of quartz mining and gold recovery as practiced in India, Mem. Geological Survey of India, V.33, pp 1-72.

HENDRICKS R.L., REISBICK F.B, MAHAFFEY E.J, ROBERTS D.B. AND PATERSON M.N.A (1969): Chemical composition of sediments and interstitial brines from the Atlantic II, Discovery and chain deeps: in HOT brines and recent heavy metal deposits in the Red Sea - E.T. Degens and D.A. Ross, ed. Springer Verlag, New York, Inc, pp 407-440.

HERGGOT G, (1980): Regional stress in Canadian Shield - Underground Rock Engineering, pp 11-15.

HU SE, AND GROVES D.I. (1988) Recent advances in under standing precambrian gold deposits, Geological Department of W. Australia, Publication No.11.

HUTCHISON R.W. (1987): Metallogeny of precambrian gold deposits: Space and time relationship. Eco. Geo. Volume 82, pp 1993-2007.

ISSACSON ED. DE. ST.Q (1963): Some problems connected with deep mining. Seminar on Gold MiningIndustry in India, Memoir No.1, Geological Society of India, Bangalore

KEAYS R.R. AND SCOTT R.B. (1976, Precious metals in Ocean Ridge basalts. Implications for basalts as source rock for gold mineralisation Eco. Geol. 71(4), pp 705-720.

KEYS R. REID (1982), Archaean gold deposits and their source rocks: The upper mantle connection Gold 82, pp 17-519.

KERICH R AND HODDER H.W. (1985): Archaean gold and base metal deposits. Evidenceofmetal seperation into independent hydrothermal systems: Geology of Canadian gold deposits, CIM, Special Volume 24, pp 144-160.

KIRMANI I.R. AND FAREEDUDDIN (1998): Wall rock alteration in Cu, Zn and Au bearing volcanogenic massive sulphide deposit at Danva District Sirohi, Rajasthan, J.G.S.I. V.52, pp 391-402.

KROGSTAD E.J., BALAKRISHNA S, MUKYAPADHY D.K., RAJAMANI V AND HANSON G.N. (1989). Pate tectonics 2.5 billion years ago, Evidence at Kolar Science Volume 243, pp 1337-1379.

LAMBERT I.B AND GROVES D.I. 1992: Early Earth evolution and Metallogeny. Handbook of stratabound and startiformore deposits. Ed. K.H. Wolf, Vol.8,pp 339-447.

LAVI R.R.T. (1980) - A Note on the sampling and ore reserve estimation in Kolar Gold Fields - BGML centenary souvenir, pp 89-94.

LAVI R.R.T. (1980) - Mysore Mine and its growth - a review, BGML Seminar on recent trends in Gold Mining Practice, pp 42-55.

LINDGREN W (1933) - Mineral deposits, pp 859.

LOUISA LAWRENCE M (1988) - Behaviour of gold within the weathering profile in the Yilgran block, W. Australia - Advances in understanding Precambrian gold deposits, Geo. Dept, University of W. Australia, Publication No.12, pp 335-351.

MACLAREN J.M. (1908) - Gold: Its Geological occurrence and Geographical distribution, Mining Journal, London.

MANN A.W. (1998) Oxidised gold deposits, relationship between oxidation and relative position of water table. Aus. Journal of Earth Science, Vol.45, No.1.

MANN H.W (1984) - Mobility of gold and silver in lateritic weathering profiles: some observation from W. Australia, Eco. Geol. V.79, pp 38-49.

MARIO CONRADA REINHARDS AND LAN DAVISON, (1990), Structural and lithological control on gold deposits in the shear zone hosted Fazenda Brasilero mine, Bahia State, Brazil, Eco. Geology. Vol.85, pp 952-967.

McKINSTRY H.E. (1948) Mining Geology, Asian Student Edition, New Delhi.

MUKHERJEE M.M. AND NATARAJAN W.K. (1985). Exploration for gold in Kolar Schist Belt, India - case histories, United Nations Inter Regional Seminar on gold exploration and development, Bangalore,pp 11.2.1.1 - 11.2.1.27.

MUKHERJEE M.M., NATARAJAN W.K. AND SHASHIDARAN, K. (1987) Economic potentiality of new gold mineralisation in South Kolar Schist Belt, J.G.S.I, V.29, pp 230-239.

NAGANNA C (1987) - Gold mineralisation in the Hutti Mining area, Karnataka, India, Eco. Geo., V.82, pp 2008-2018.

NARAYANASWAMI S, ZIAUDDIN M, AND RAMACHANDRA A.V. (1960) - structural control and localisation of gold bearing lodes, Kolar Gold Fields, India, Eco. Geol. 55, pp 1429-1459.

NARAYANASWAMY S, ZIAUDDIN M, RAMACHANDRA A.V. AND GUPTA B.D. (1959) - Geological exploration for gold bearing lodes in Kolar Gold Fields, Mysore State and recommendations for exploration of Champion lode, Mundy's lode and sulphide bearing western lodes in Champion Reef and Mysore Mine, Geological Survey of India, F.S. 1957-58 (unpublished)

NATARAJAN W.K., DAVY D.R. AND MUKHERJEE M.M. (1974) (F.S. Report) Investigation for gold in the western part of Kolar Gold Field. Un published.

NEKRASOV I. YA (1996) - Geochemistry, Mineralogy and genesis of gold deposits.

NESBITT R.W., SUN S.S. AND PURVIS P.C. (1979) - Komatiites: Geochemistry and Genesis, Canadian Mineralogist, V.17, pp 165-189.

NICHOLAS A (1986) - Principles of Rock formation, Discontinuous deformations, structures and interpretations, Holland, pp 51-57.

PARRISH I.S. (1983) - UNDP Report, submitted to BGML.

PARRISH I.S., MULLEN T.V. AND PARRISH B.S. (1985) - The golden Challenge, UN Inter regional seminar on gold exploration and development, Bangalore, pp 1.1.1-1.1.28

PESHWA S.C.R. (1997): Underground maping in Honcocks Shaft (Mysore Mine) and in Glens Shaft (Champion Mines), BGML.

PHILLIPS KEEREY AND FREDICK JVIN (1990) Global tectonics, Black wall Scientific Publication, pp 19.

PRETORIOUS D.A. (1982) Gold in Proterizoic sediments of S. Africa, Systems, Paradigious and models, Hand Book of stratabound and stratiform ore deposits, Ed. K.F. Wolf.

PRYOR T (1922) - Report of the underground Geology of Nundydroog Mine, K.G.F. pp. 1-24.

PRYOR. T (1923) the underground Geology of the Kolar Gold field - Transactions, Inst. Min. Met. 33, pp 45 - 115 and 131 - 135.

PUDDEPHAST R.J., ZHOV S, AND FYBE W.S. 1989 - Transport of gold in high temperature, low pressure, Gas phases with Cl_2, Co_2, H_2o - a clue to gold mineralization for the lower crust, World Gold 89, pp 123 - 129.

PYKE D.R. (1976): Relationship between gold mineralization and ultramafic volcanic rocks in the Timmins area : Northern Ontario CIM Bulletin 69 (773), pp 79-87.

PYKE D.R. (1981) Relationship of gold mineralization to stratigraphy and structure in Timmins and surrounding area: Genesis of Archaean Volcanic hosted gold deposits, Sumposium held at University of Waterloo, Ontario Geo. Survey, Miscellaneous paper 97, pp 1-15.

RADHAKRISHNA B.P. (1996): Mineral Resources of Karnataka, Geo. Soc. of India, pp 214-279.

RADHAKRISHNA B.P. AND VAIDHYANATHAN R. (1994): Geology of Karnataka. Goldbearing schist belts of eastern Karnataka, pp 57 - 72.

RAJAMANI V, SHIVAKUMAR K, HANSON G.N. AND GRANTHA R.W. (1981) - Petrogenesis of amphibolites in Kolar Schist belt, India - A preliminary report Journal. Geol. Soci. of India, V. 22, pp 470 - 487.

RAJAMANI V, SHIVAKUMAR F, HANSON G.N. AND SHIREY A.B. (1985) - Geochemistry and petrogenesis of amphibolites of Kolar Schist Belt, south India, Evidence of Komatiitic magma derived by low percentages of melting of mantle, Jour. Pet. V.26, pp 92-123.

RAJAMANI V, KROGSTAD E.J., HANSON G.N. AND BALAKRISHNA S (1987) - Are patna and Bisanatham granites (adjoining the Kolar Schist belt) cogenetic ? Jour. Geo. Soc. of India, Vol 30, No.2, Aug. 1987,pp 98-105.

RAJAMANI. V., (1988): The Kolar Schist Belt, Worship on the Deep Continental crust of South India, Field guide pp 24-26.

RAJAMANI.V., SHIREY S.B. AND HANSON G.N., (1988) - Fe rich Archean Tholeiites derived from melt enriched mantle sources: Evidence from the Kolar Schist Belt, S. India, pp 1-32.

RAJAMANI.V., 1996, Gold mineralisation in Kolar Schist Belt, National workshop on exploration and exploitation of gold resources of India, NGRI, Hyderabad, pp 255-261.

RAJU K.K. (1996) - Geology, mineralization and structural controls in Hutti gold deposits, National workshop on exploration and exploitation of Gold resources of India, NGRI, Hyderabad, pp 71-88.

RAMAKRISHNA REDDY. P., (1980), Provenance studies for gold in the northen part of the Kolar Schist belt and Geomorphological studies for locating favourable zones for placer gold concentration in Palar and Ponniyar river basins. Seminar on Recent trends in Gold Mining Practice, B.G.M.L., pp 129 - 135.

RAO, M.H.R., (1980) - A review of mining practice in Kolar Gold Mines in retrospect and prospect. Seminar on recent trends in Gold Mining Practice, BGML, pp 92-108.

RAO, P.S. AND REDDY U.S. (1985) - Geology of the Gold deposits of India, U.N. Inter Regional Seminar on Gold exploration and development, Bangalore, pp 1.2.1-1.2.33

RAVAL U. (1996) - some geodynamical consideration of fluid processes in gold mineralization, National workshop on exploration and exploitation of gold resources of India, NGRI, Hyderabad, pp 284-300.

REDDY, V.D. PRASAD C.V.R.K. (1979) - Paleomagnetism of the dykes for Kolar Gold Mines, India. J.G.S.I, V.20, pp 489 - 500.

ROBERT F, SHEAHON P.A. AND GREEN S.B. (1990): Greenstone Gold and crustal evolution, Geologists Association of Canada, Proceedings of the workshop held at Voldor, Qubeck, pp 1-50.

SAFANOV YU.G., RADHAKRISHNA B.P., KRISHNA RAO B, VASUDEV V.N., KRISHNAM RAJU K, NOSIK L.P. AND PASHKOV Y.N. (1980) - Mineralogical and Geochemical features of endogene gold and Copper deposits of S. India. J.G.S.I V. 21, pp 365-378.

SAFANOV YU.G. GENKIN, A.D. VASUDEV V.N., KRISHNA RAO B (1984) - Genetic aspect features of gold deposits at Kolar, Dharwar Craton, I,J.G.S.I, V.25(3), pp 145- 154.

SAHA A.K., RAO, S.V.L.N., AND SHANKAR SEN (1983): Operation Research Project on gold mineralisation in Kolar Gold Field, Group I Report.

SANKARAN A.V. (1998) Drifting mantle plumes, mobile hot spots and island chain, Current science, Vol.75, No.2, 25 July 98, P 85-89.

SARMA D.D. (1983) Utilisation of Operations Research Techniques in and around Kolar Gold Fields, Group II Report.

SIVASIDDAIAH.N., AND RAJAMANI, V., (1989) - Geochemistry and genesis of gold deposits of Archaean Kolar Schist belt India, Eco. Geol. Vol. 84, pp 1-73.

SIVASIDDAIAH,N AND RAJAMANI,V., (1989) - The geological setting, mineralogy, Geochemistry and genesis of gold deposits in the Archaean Kolar Schist belt, South India, Eco. Geol. V.48, pp 1152 - 1566.

SIVASIDDAIAH,N., HANSON,G.N. AND RAJAMANI,V., (1994) - Rare earth element evidence for syngenetic origin of an Archaean stratiform gold sulphide deposit, Kolar Schist belt, S. India, Eco. Geol. V 89, pp 1152 - 1166.

SRINIVASAN,R. AND SRINIVASAN, B.L., (1972): Dhwarwar stratigraphy, J.G.S.I, V.13, pp 72-83.

SRINIVAS K, (1980): A note on the exploration carried out to trace the southern extension of the Champion lode in Mysore Mine, BGML Centinery Souvenir, pp 27-29.

SRIVASTAVA N. (1986) - Geochemistry and genesis of gold mineralization in the Precambrians of Kolar Schist Belt, S. India, Ph.D. Thesis J.N.University, Delhi.

SUBBARAMAN J.V. (1980) Stoping gaps and their geological significance in and around crockers shaft, Mysore Mine, BGML - Centenary Seminar on Recent trends in gold mining practices, pp 138-145.

SUBBARAMAN J.V. (1990) - Scope for search and Research in gold exploration in and around Kolar Gold Field. Nat. Sem. on Recent Trends in Exploration, Exploitation and Conservation of minerals of India, pp 13-19.

SUBBRAMANYAM V. SHARMA B.S AND RAO M.S. (1991): Geochemistry, Ore petrology and Genesis of gold mineralization in Kolar Greenstone Belt, Karnataka, Geol. Survey. of India, Bul. Ser.A, No.52, pp 1-113.

SWAMINATH J. AND RAMAKRISHNA M (Editor) (1981): Early Pre-Cambrian supra crustals of Southern Karnataka, Mem. GSI V.112, pp 221-245.

TEWEDLE HAILE (1989) - Geology of Kolar Gold Field with special emphasis on the fluid inclusion studies in gold sulphide lode, M.S.c. Thesis, I.I.T., Kharagpur.

VILJOEN R.P., SAGGAR R, AND VILJEON M.J. (1970) - some thoughts on the origin and processes responsible for the concentration of gold in the early Precambrians of S. Africa, Min. Deposita 5, pp 164-180.

VILJOEN M.J. (1984) - Archaean gold mineralisation and Komatiites in Southern Africa, Geo. Soc. Zimbabwe, Special Publication, No.1, A.A. Balkemo, Rotterdam, pp 595 - 628.

VISWANATHAN S (1974) - Basaltic Komatiitic occurrence in Kolar Gold Field of India, Geol.Mag.111, pp 353-354.

VISWANATHA M.N. AND RAMAKRISHNA M (1976) - The Pre Dharwarian supracrustal rocks of sargur schist complex in Southern Karnataka and their tectonic and metamorphic significance, Indian Mineralogist, 16, pp 48-65.

VISWANATHAN S (1979) - Komatiite occurrence in the Kolar Greenstone Belt, Karnataka state India, Their Metallogenic significance. Tectonics and metallogeny of South India, GSI, Mis. Publ.39(11), pp 95-101.

WAGUE PAM AND CAMERON E.M. (1995): Processes in the extraction of gold from a deep crustal shear zone following a change in the Tectonic stress. Precambrian 95, Abstract.

WINDLEY BRIAN F (1995) - The evolving continents, Published by John Wiley & Sons, New York.

YAKUSHOVA,A.F.(1986),Geology with elements of Geomorphology,(Translated from Russian to English by C.C.EGOROV). p21.

ZEEGERNS AND LEDUC.C., - Geochemical exploration for gold in Temperate, arid and Semi arid and rain forest terrains - Gold metallogeni and exploration, Chapter 10, pp 10.1 - 10.6

ZEMEVE ASRES, Geology of Kolar Gold Fields with special reference on the ore mineralogy and petrology, M.Sc. Thesis, I.I.T., Kharagpur, 1989.

ZHOU, YONG-ZANG, LU, HANG-SONG, GUHA, JAYANTHA (1992): Geological characteristics of hydrothermal fluid inclusions of Hetai Gold field, S. China, 29th international Geological Congress, Koyoto, Japan.

ZIAUDDIN M AND NARAYANASWAMY S (1974) - Gold resources of India, Geol. Surv. of India, Gulletin Series A, Eco. Geol 38(1), pp 2-7.